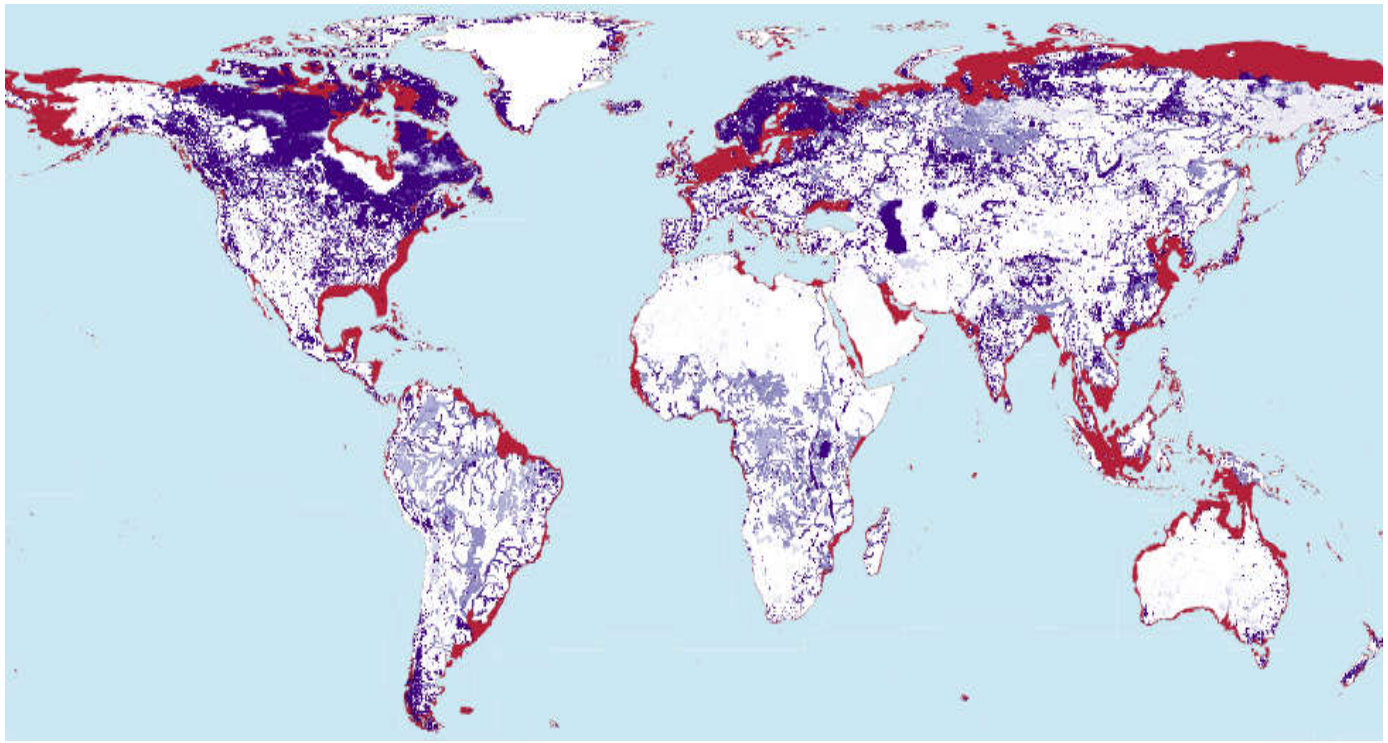
The hyperspectral sensors DESIS for aquatic ecosystems monitoring – a sensitivity study

Nicole Pinnel, Peter Gege, Anna Göritz

Outline

- Aquatic ecosystem monitoring
- DLR Earth Sensing Imaging Spectrometer (DESIS)
- Sensitivity analysis for determination of water parameters
- Comparison of simulated spectra and real DESIS data.
- Conclusion

Aquatic ecosystem monitoring - global relevance



Coastal regions with water depth < 50 m

Inland wetlands, lakes, rivers

Global distribution of coastal and inland aquatic ecosystems (UNEP- WCMC, 2005)

Aquatic ecosystem monitoring

- Key parameters
  - Concentrations: phytoplankton pigments, suspended matter, dissolved organic matter (CDOM)
  - Optical properties: phytoplankton fluorescence, absorption, backscattering, transparency
  - Others: water depth, bottom substrate type and coverage

- Sensor requirements
  - Spectral
  - Radiometric
  - Geometric
  - Temporal coverage

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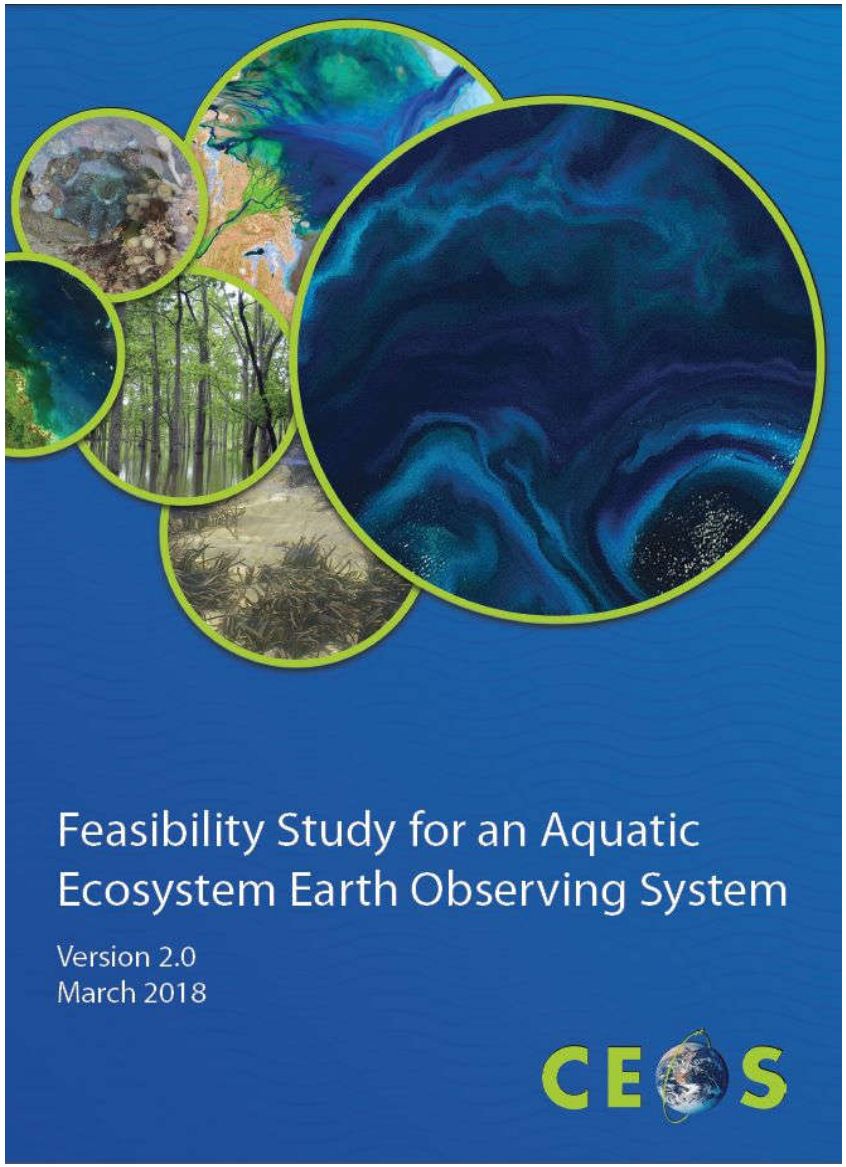
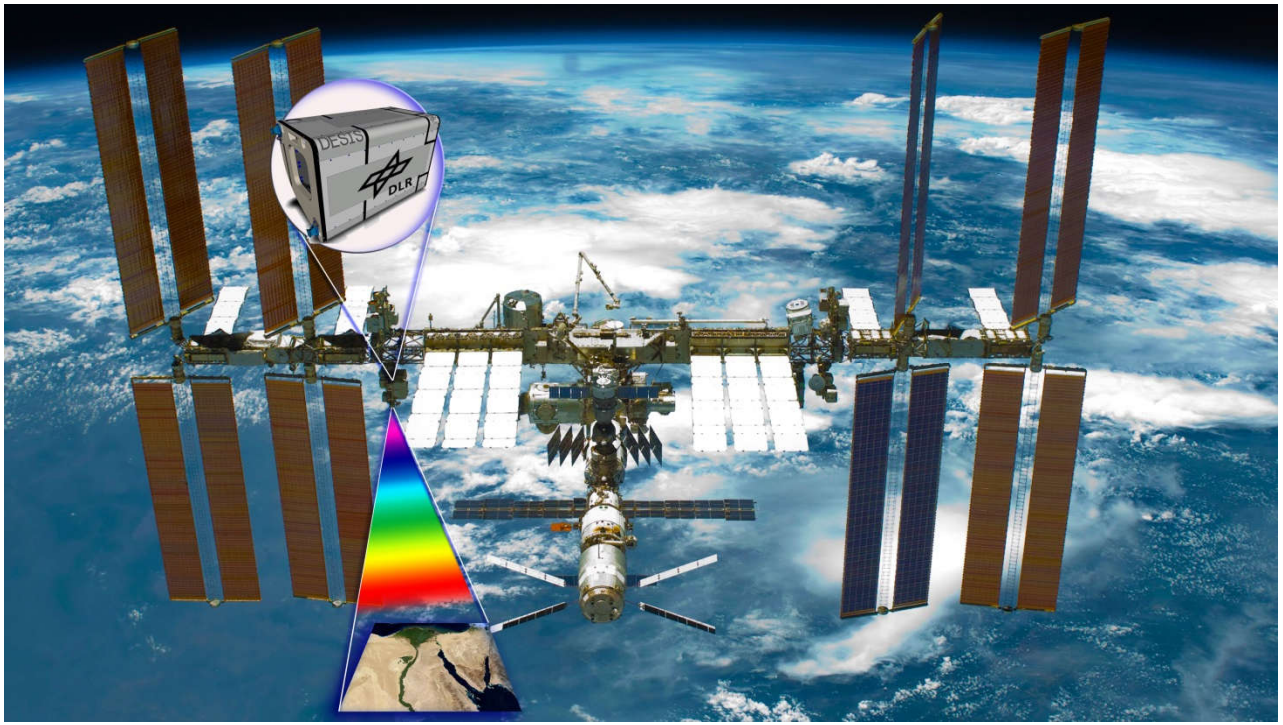


DLR Earth Sensing Imaging Spectrometer (DESIS)



Orbit: ISS (~400 km)

Coverage: 55° N to 52° S

Tilting: -45° to +5° (cross track)
-40° to +40° (along track)

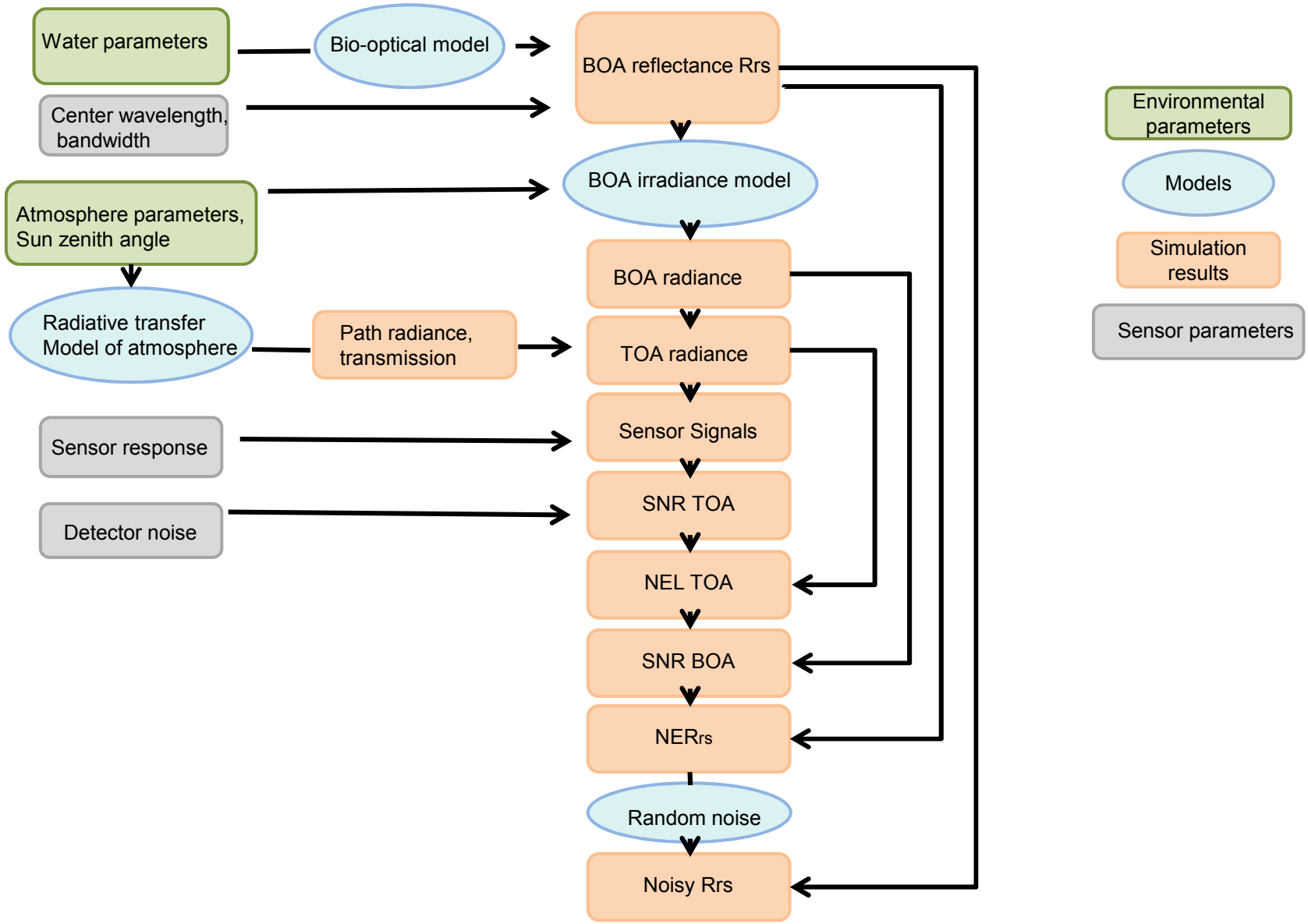
Spectral range: 420 to 1000 nm

Spatial: 30 m x 30 m

Swath: 30 km @400 km

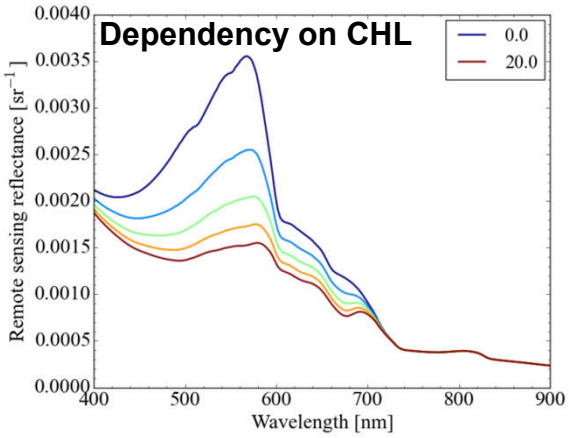
DLR

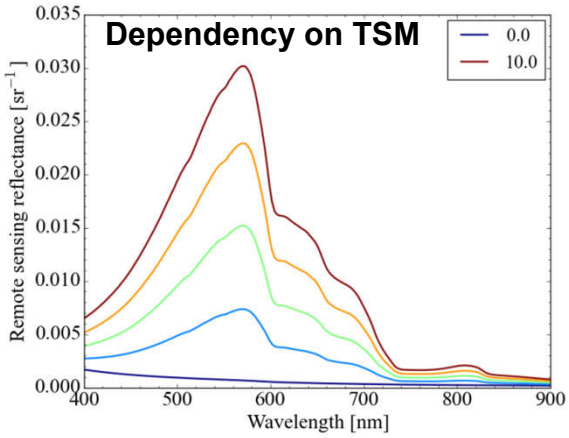
Flow chart forward simulations

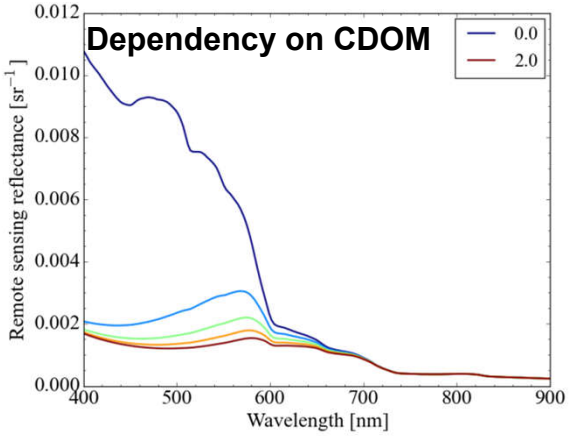


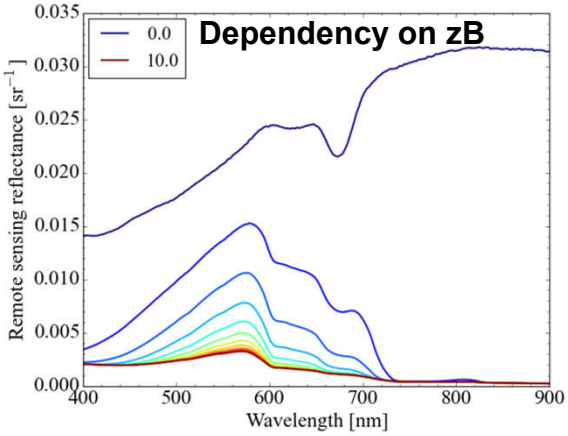
Sensitivity analysis for determination of water parameters

Variability of remote sensing reflectance (sr^-1)









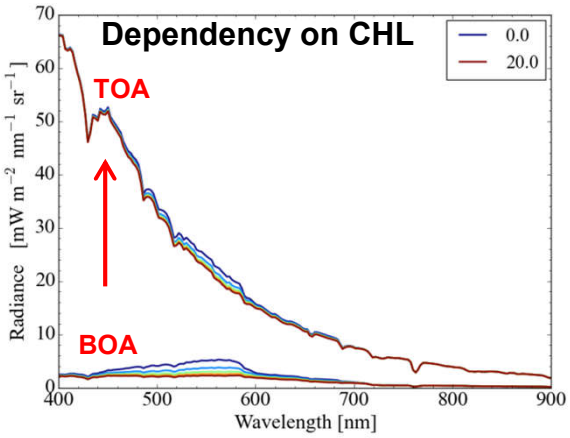
Courtesy C. Giardino, CNR

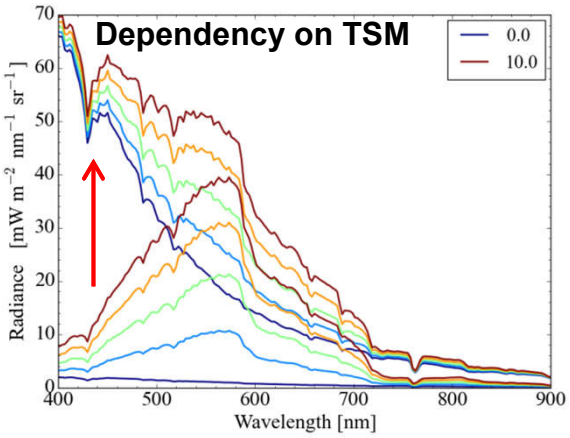
Scenario	Deep water	Shallow water
θ_{sun} [deg]	30, 60	30, 60
VIS [km]	100, 10	100, 10
TSM [mg /l]	**1** (0.1-10)	1
CHL [µg /l]	**2** (0.2-20)	2
a_{CDOM} [1/m]	**0.5** (0.2-2)	0.5
S_{CDOM} [nm^{-1}]	0.014	0.014
zB [m]	1000	**1** (0-10)

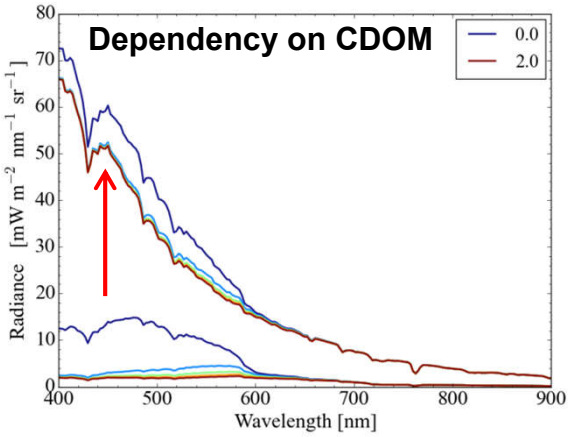
No sunglint, but skyglint included

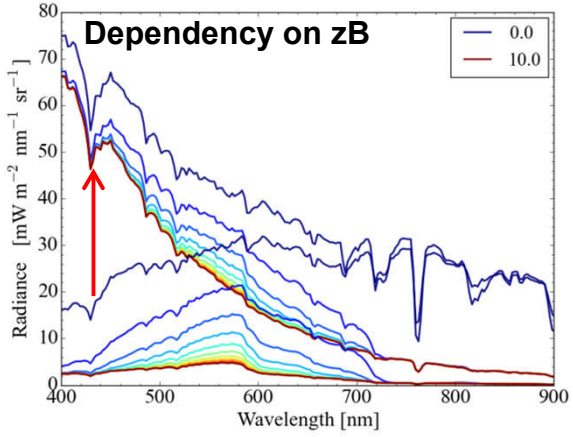
Sensitivity analysis for determination of water parameters

Range of upwelling radiance at top of atmosphere and bottom of atmosphere









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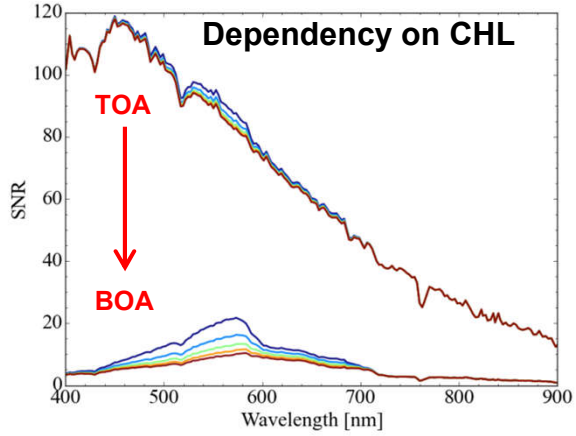
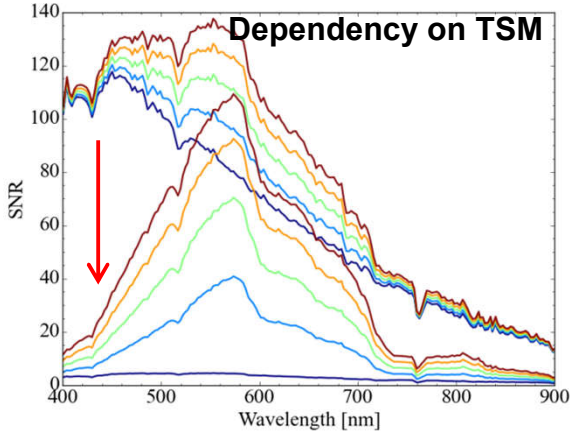
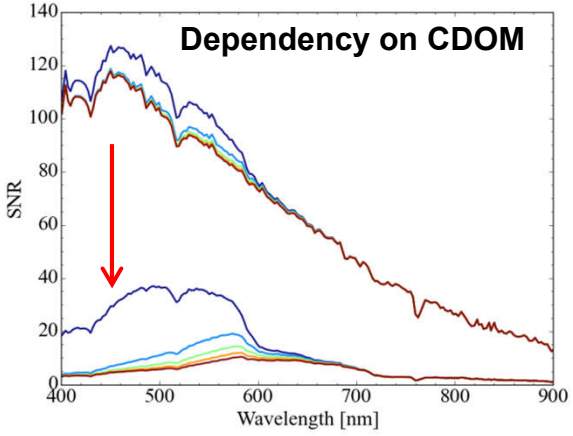
No sunglint, but skyglint included

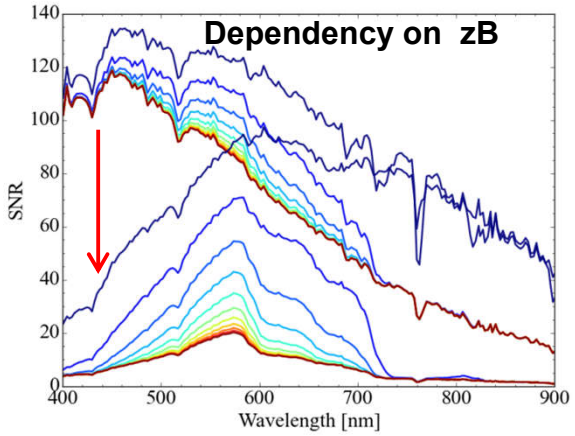
Sensitivity analysis for determination of water parameters

SNR at bottom of atmosphere (BOA) and top of atmosphere (TOA)









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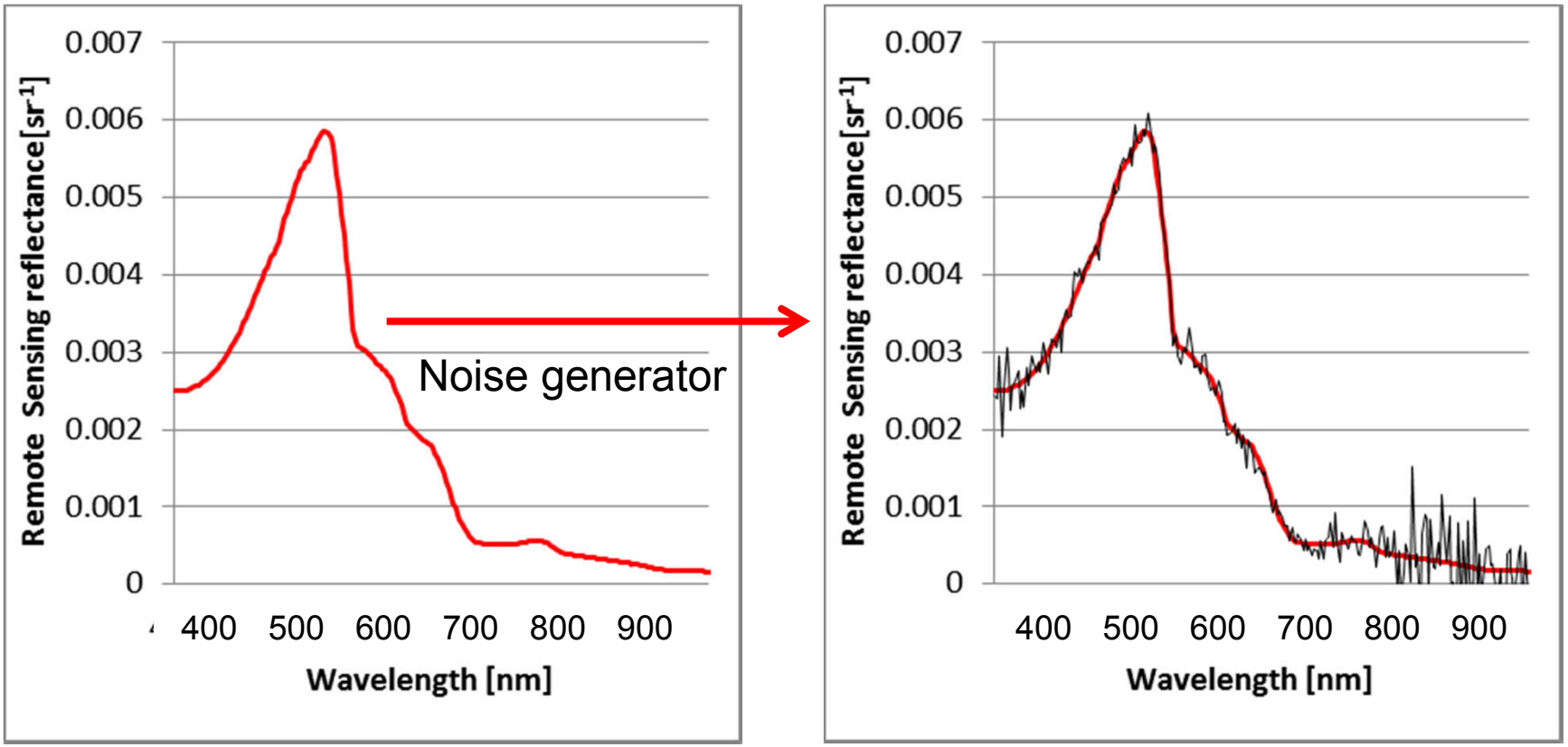
No sunglint, but skyglint included

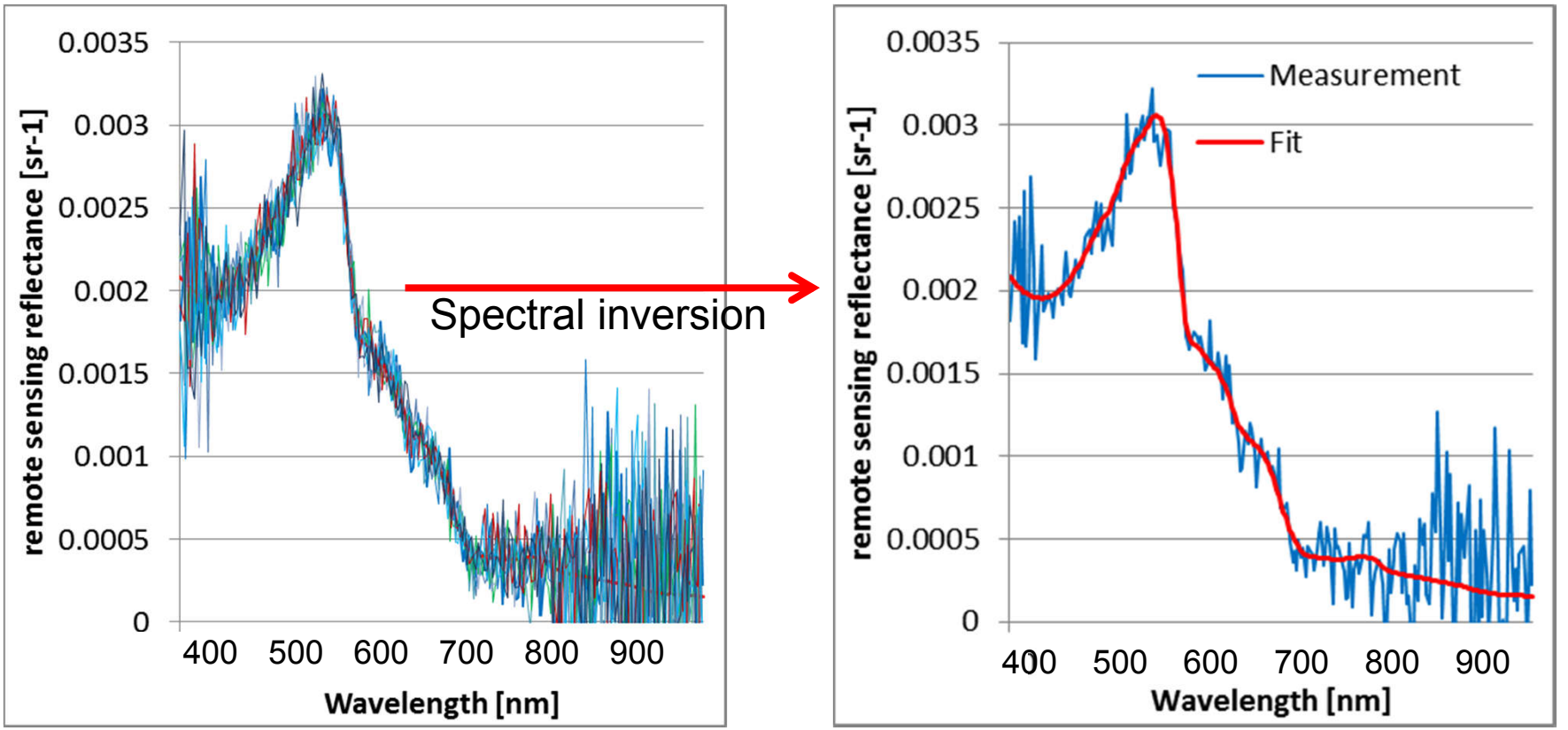
Sensitivity analysis for determination of water parameters

Simulation of noisy reflectance spectra



Inversion of water parameters from simulated spectra

Noise simulated DESIS spectra



Scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**1**(0.2-10.0)	**5**(1-10)	**1**(0.2-20.0)	**10**(5-15)
a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
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Scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
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a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

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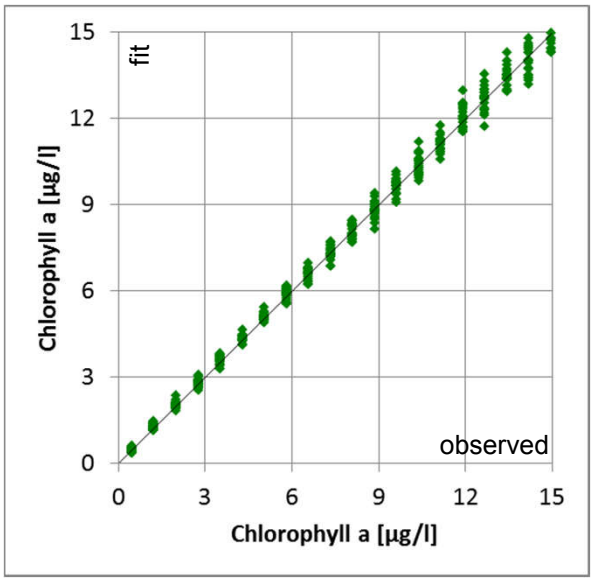
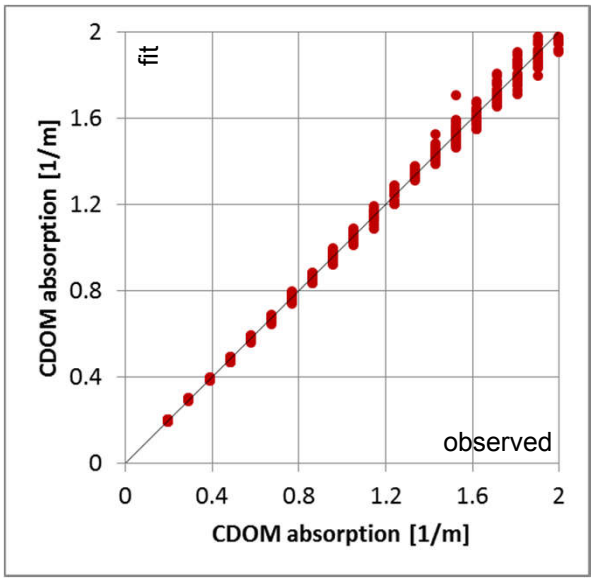
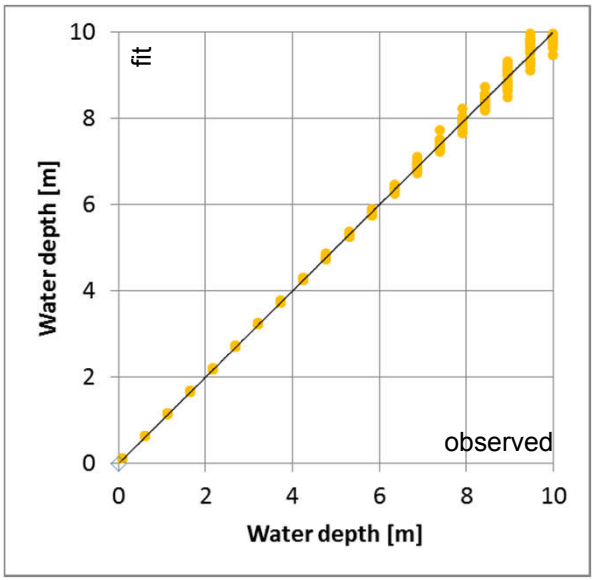
Inversion Results

Scenario X- Low TSM (Lake Constance) 1 fit parameter



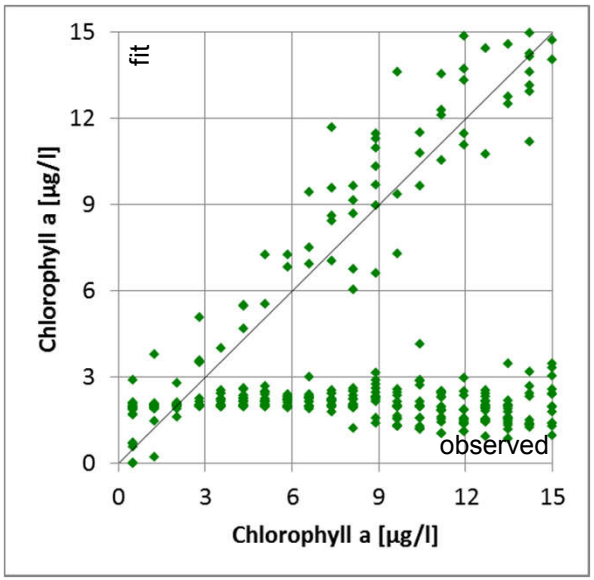


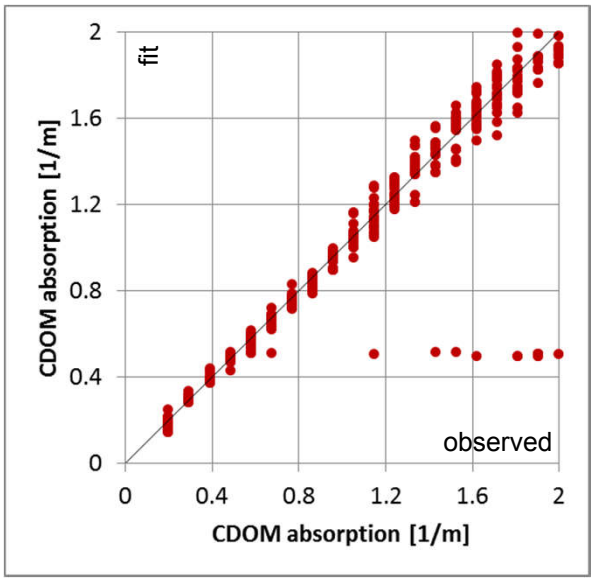


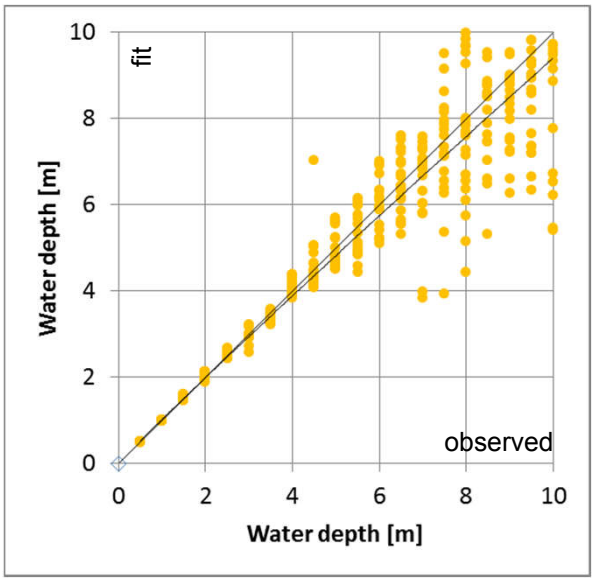
θ_{sun} [deg]	**30**	TSM [mg /l]	**1**	a_{CDOM} [1/m]	**0.5** (0.2-2)
VIS [km]	**100**	CHL [mg /l]	**2** (0.5-15)	zB [m]	**1** (0-10)

Inversion Results

Scenario X- Low TSM (Lake Constance) 3 fit parameter



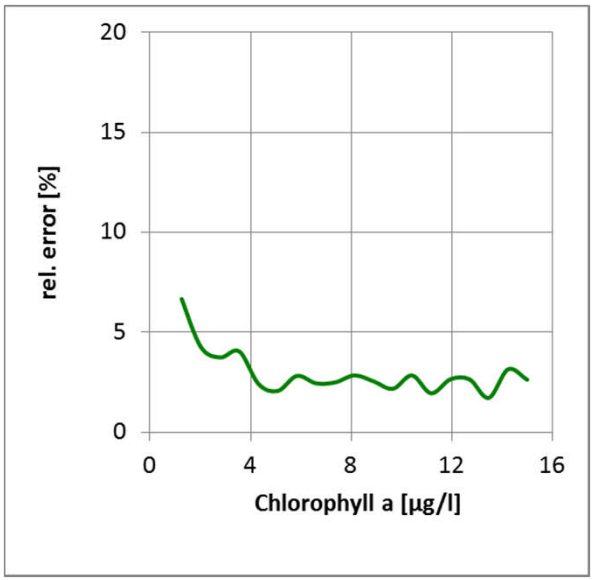


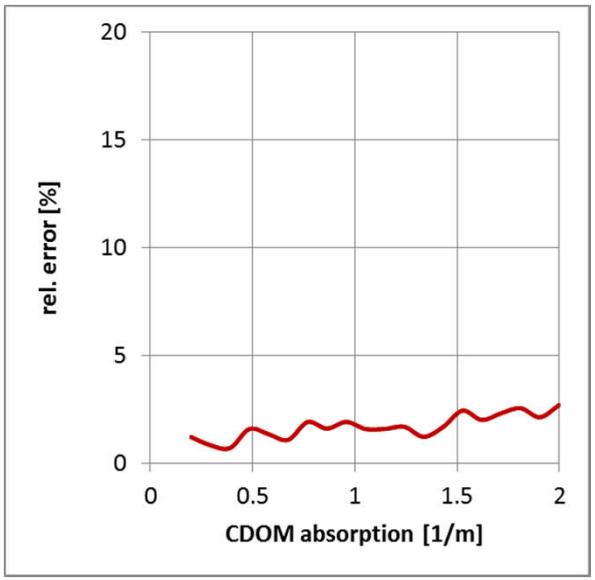


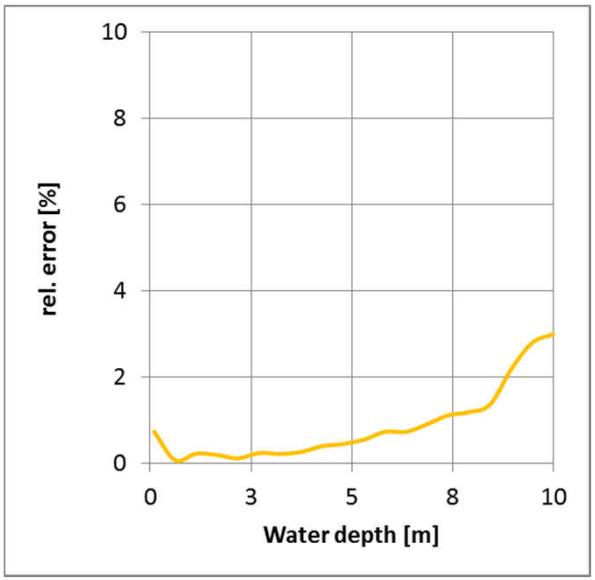
θ_{sun} [deg]	**30**	TSM [mg /l]	**1**	a_{CDOM} [1/m]	**0.5** (0.2-2)
VIS [km]	**100**	CHL [mg /l]	**2** (0.5-15)	zB [m]	**1** (0-10)

Inversion Results

Scenario X- Low TSM (Lake Constance) 1 fit parameter



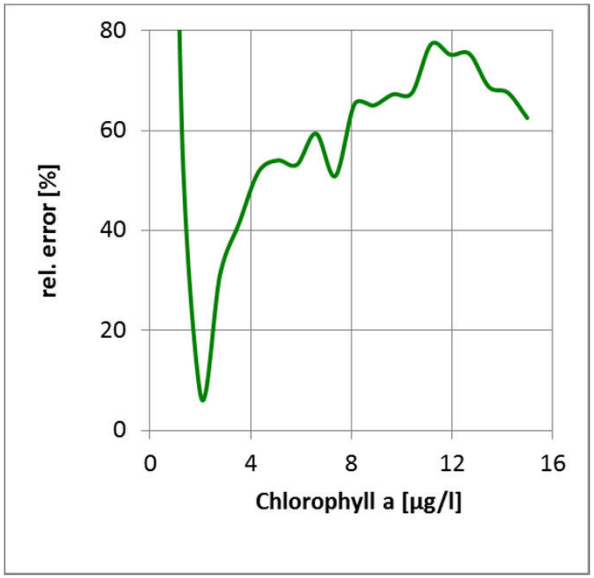


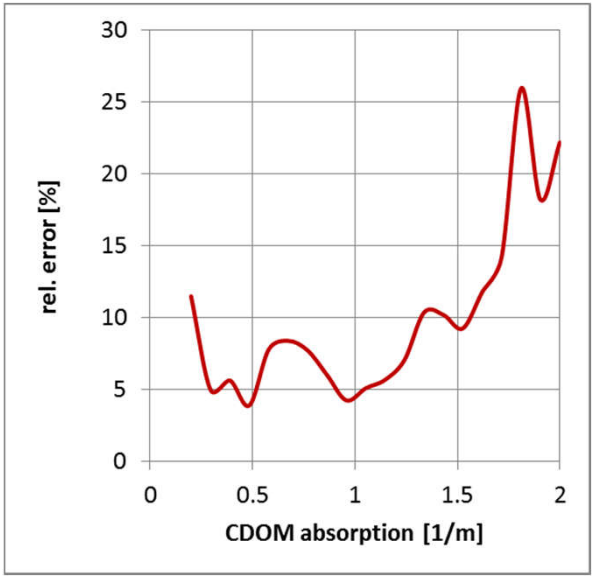


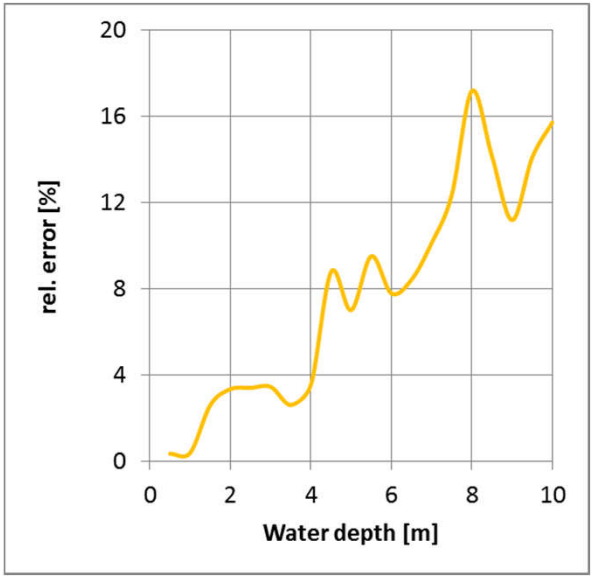
θ_{sun} [deg]	**30**	TSM [mg /l]	**1**	a_{CDOM} [1/m]	**0.5** (0.2-2)
VIS [km]	**100**	CHL [mg /l]	**2** (0.5-15)	zB [m]	**1** (0-10)

Inversion Results

Scenario X- Low TSM (Lake Constance) 3 fit parameter







θ_{sun} [deg]	**30**	TSM [mg /l]	**1**	a_{CDOM} [1/m]	**0.5** (0.2-2)
VIS [km]	**100**	CHL [mg /l]	**2** (0.5-15)	zB [m]	**1** (0-10)

Scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
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CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

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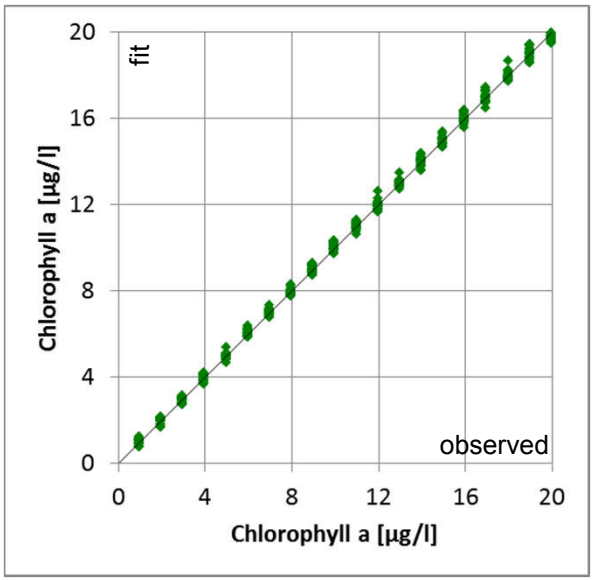
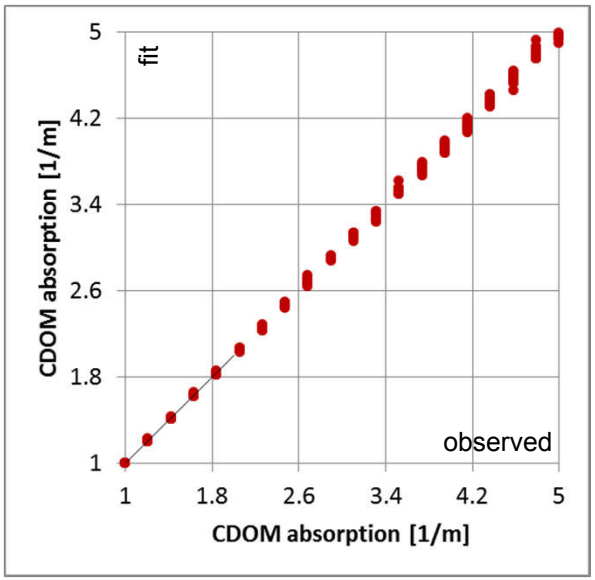
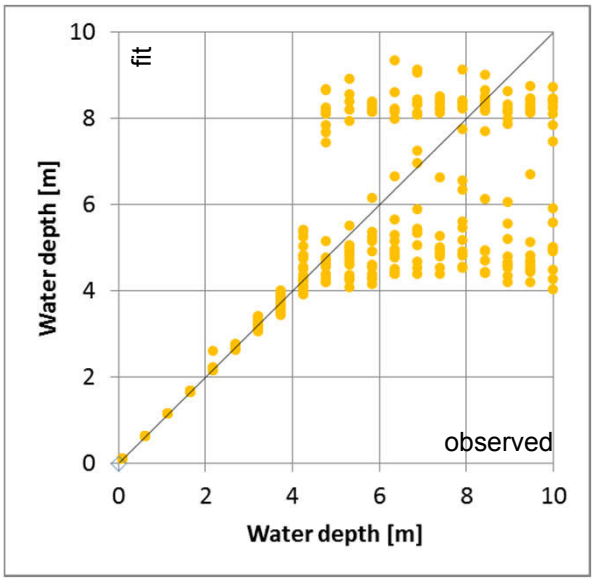
Inversion Results

Scenario X+ High TSM (Lake Peipsi) 1 fit parameter



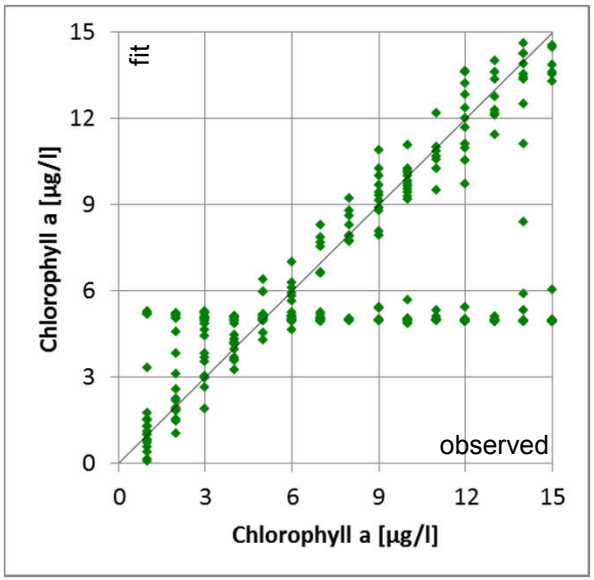


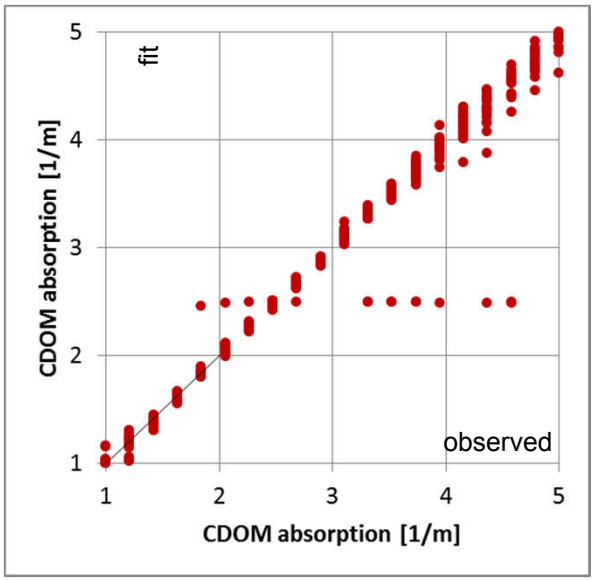


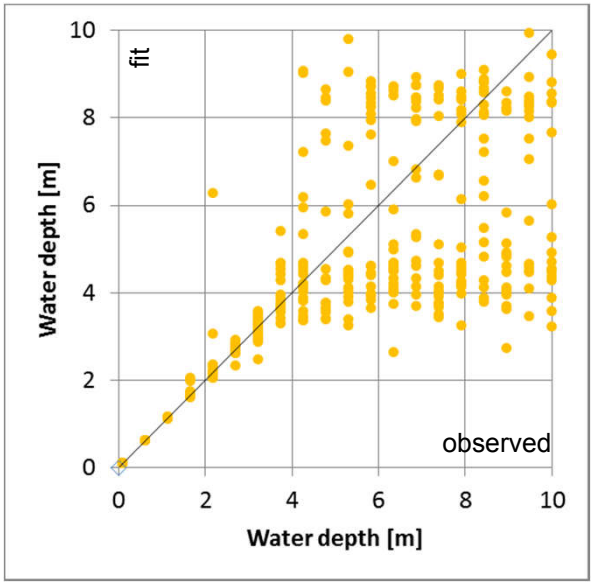
θ_{sun} [deg]	**30**	TSM [mg /l]	**5**	a_{CDOM} [1/m]	**2.5** (1-5)
VIS [km]	**100**	CHL [mg /l]	**5** (1-20)	zB [m]	**1** (0-10)

Inversion Results

Scenario X+ High TSM (Lake Peipsi) 3 fit parameter







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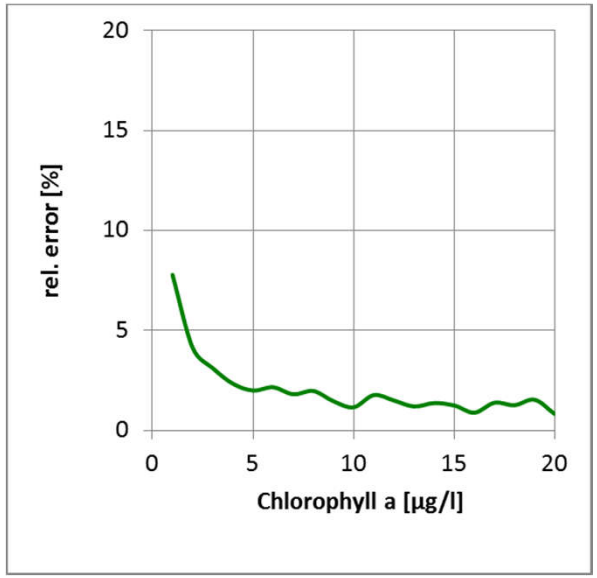
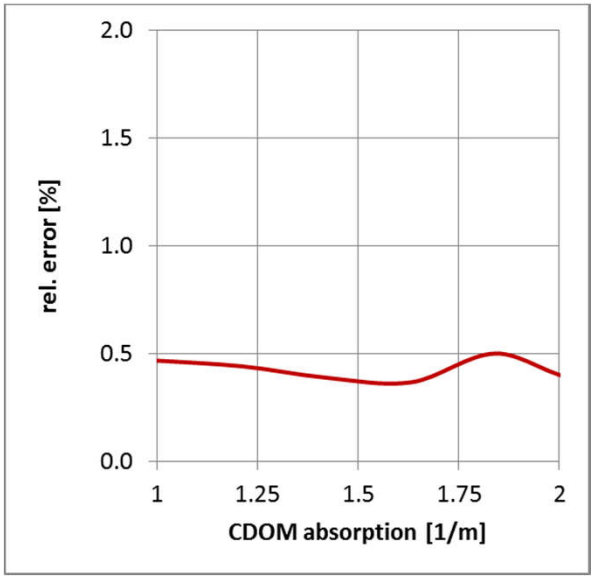
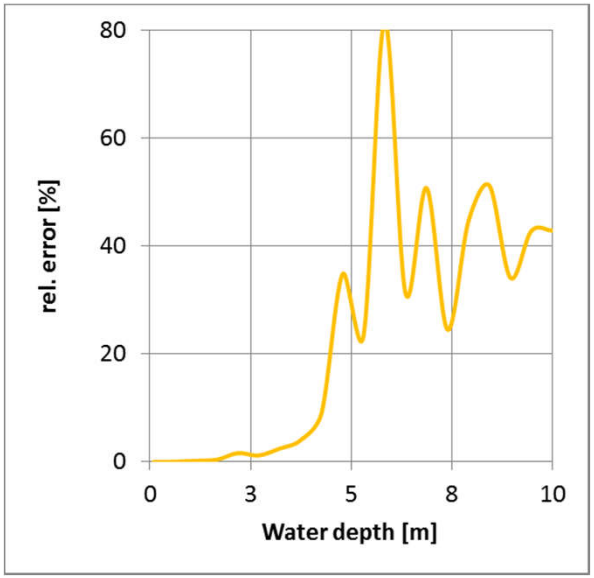
Scenario X+ High TSM (Lake Peipsi) 1 fit parameter



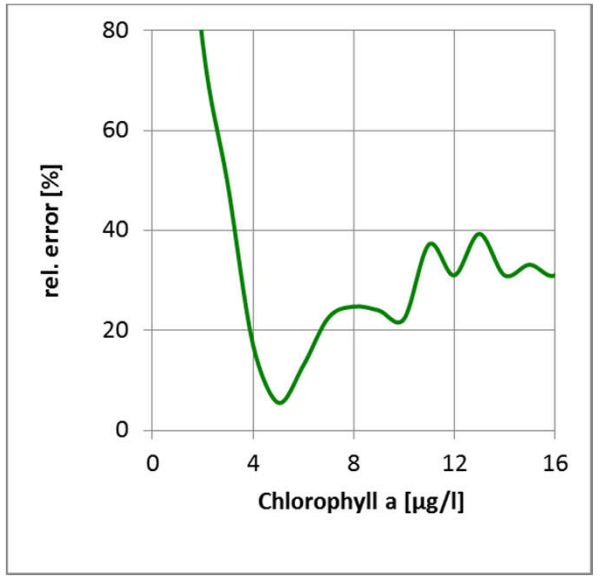


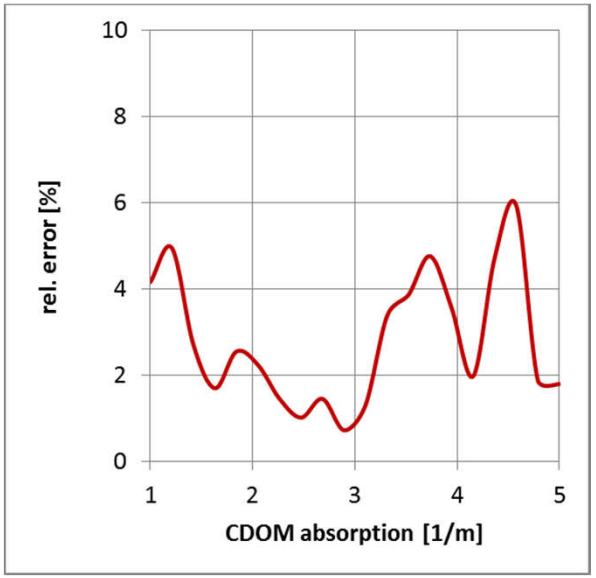


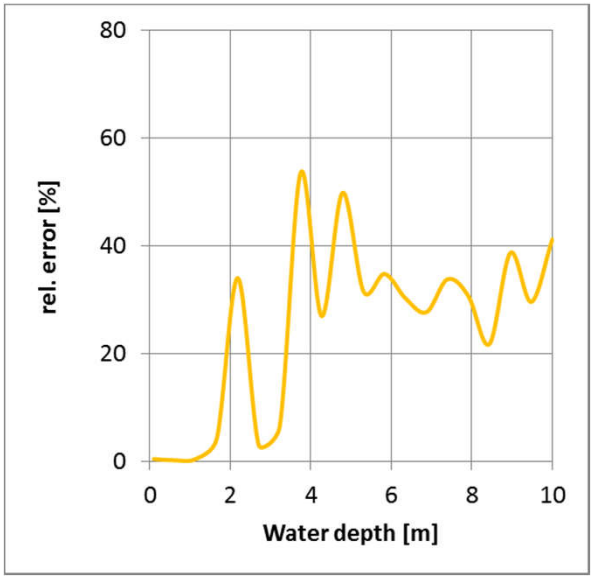
θ_{sun} [deg]	**30**	TSM [mg /l]	**5**	a_{CDOM} [1/m]	**2.5** (1-5)
VIS [km]	**100**	CHL [mg /l]	**5** (1-20)	zB [m]	**1** (0-10)

Inversion Results

Scenario X+ High TSM (Lake Peipsi) 3 fit parameter







θ_{sun} [deg]	**30**	TSM [mg /l]	**5**	a_{CDOM} [1/m]	**2.5** (1-5)
VIS [km]	**100**	CHL [mg /l]	**5** (1-20)	zB [m]	**1** (0-10)

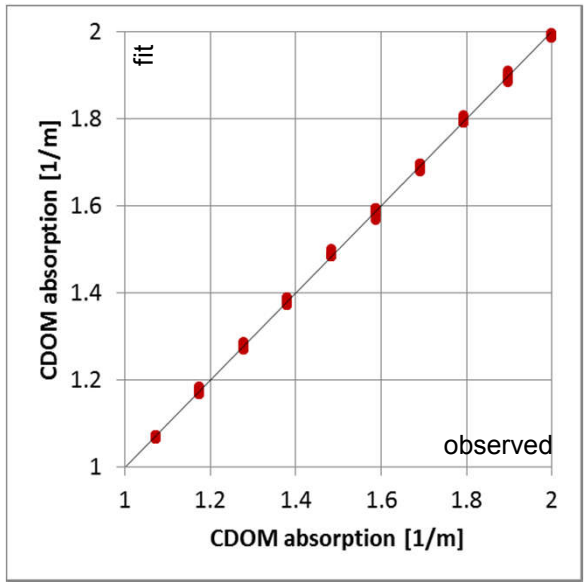
Scenarios

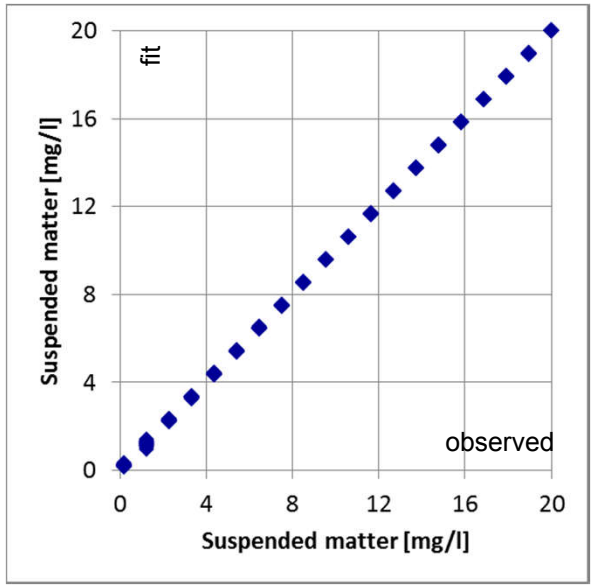
Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**1**(0.2-10.0)	**5**(1-10)	**1**(0.2-20.0)	**10**(5-15)
a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

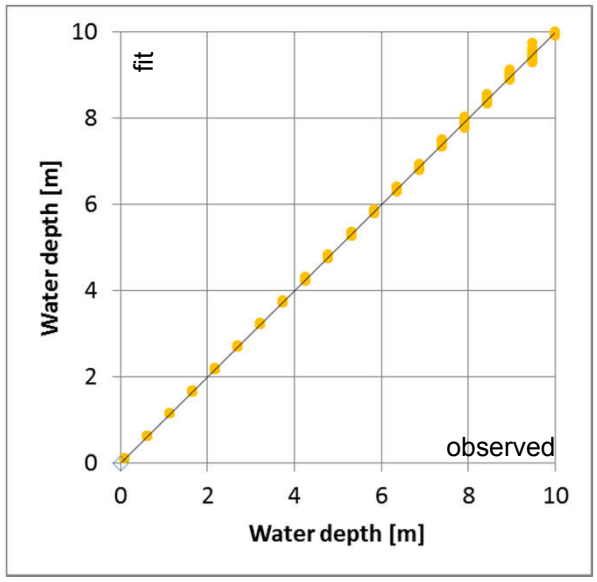
Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

Inversion Results

Scenario C- Low Chl (L. Garda) 1 fit parameter



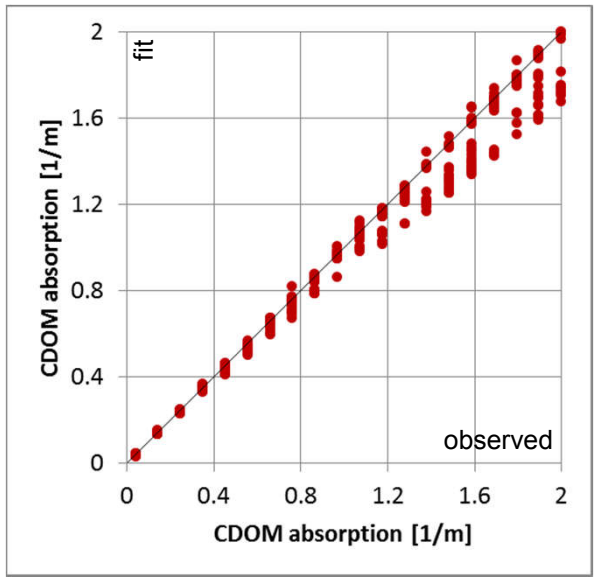


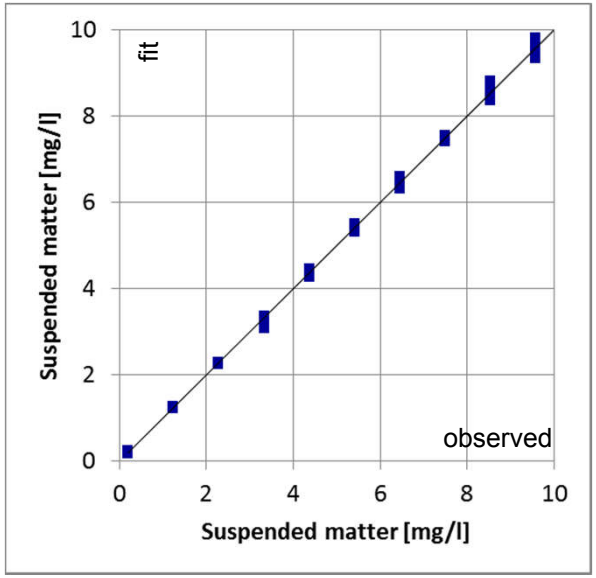


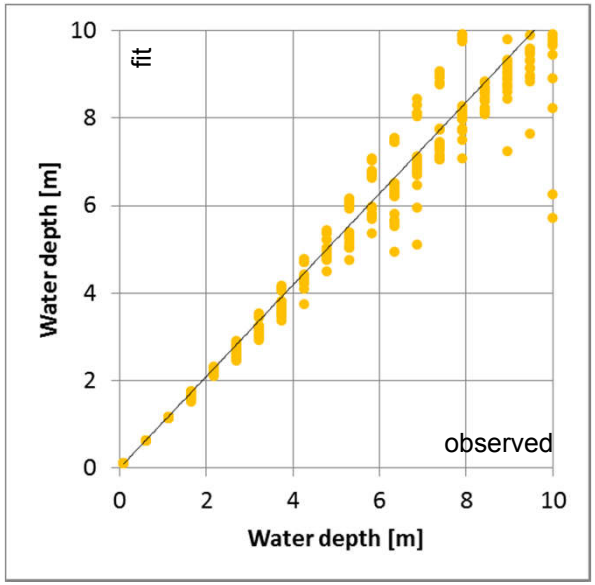
θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-20)	a_{CDOM} [1/m]	**0.1**
VIS [km]	**100**	CHL [mg /l]	**1**	zB [m]	**1** (0-10)

Inversion Results

Scenario C- Low Chl (L. Garda) 3 fit parameter







θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-20)	a_{CDOM} [1/m]	**0.1**
VIS [km]	**100**	CHL [mg /l]	**1**	zB [m]	**1** (0-10)

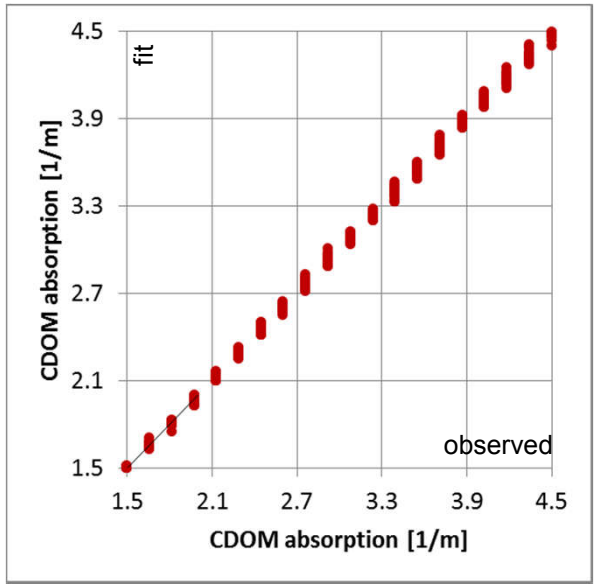
Scenarios

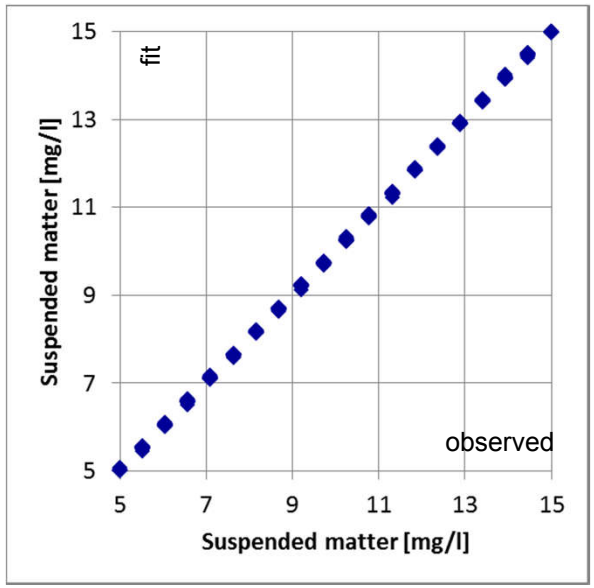
Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**1**(0.2-10.0)	**5**(1-10)	**1**(0.2-20.0)	**10**(5-15)
a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

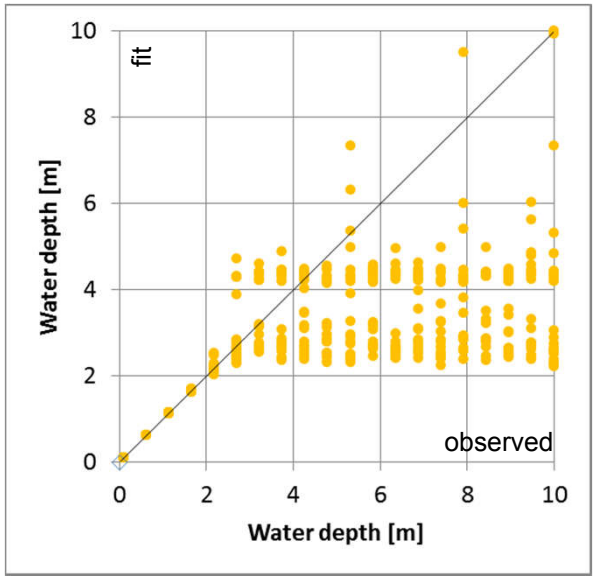
Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

Inversion Results

Scenario C+ High Chl (2 Finnish Lakes) 1 fit parameter



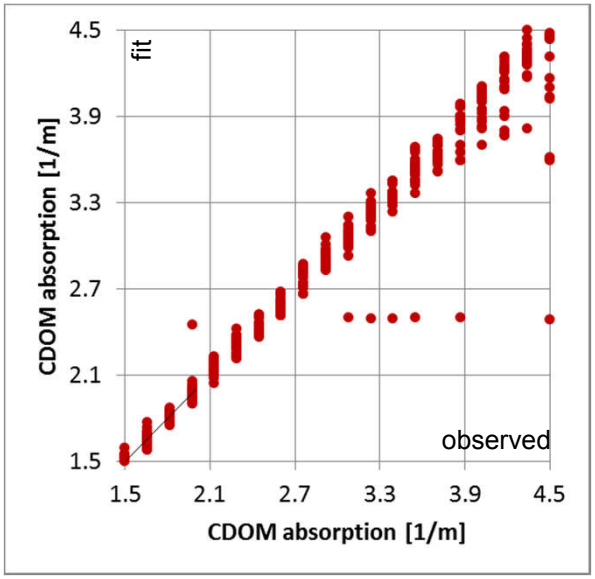


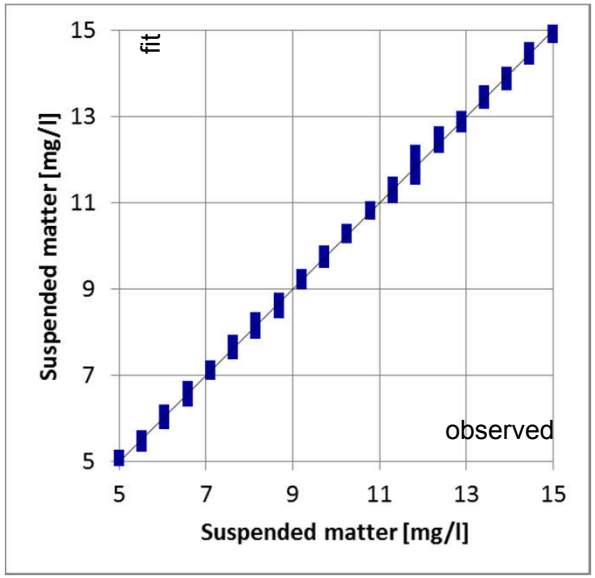


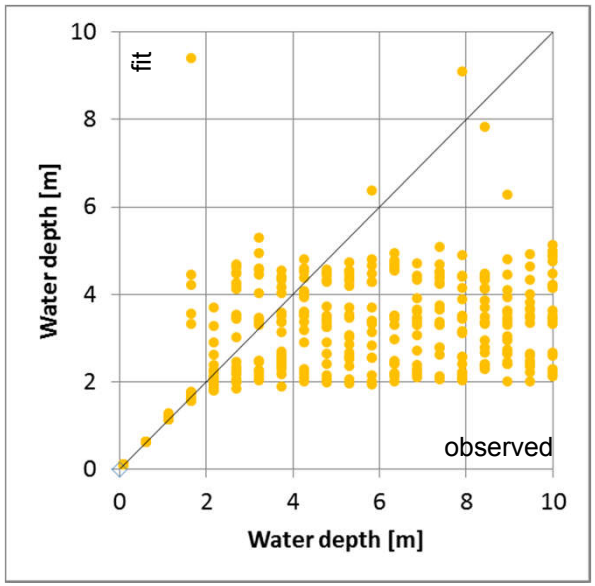
θ_{sun} [deg]	**30**	TSM [mg /l]	**10** (5-15)	a_{CDOM} [1/m]	**2.5** (1.5-4.5)
VIS [km]	**100**	CHL [mg /l]	**40**	zB [m]	**1** (0-10)

Inversion Results

Scenario C+ High Chl (2 Finnish Lakes) 3 fit parameter



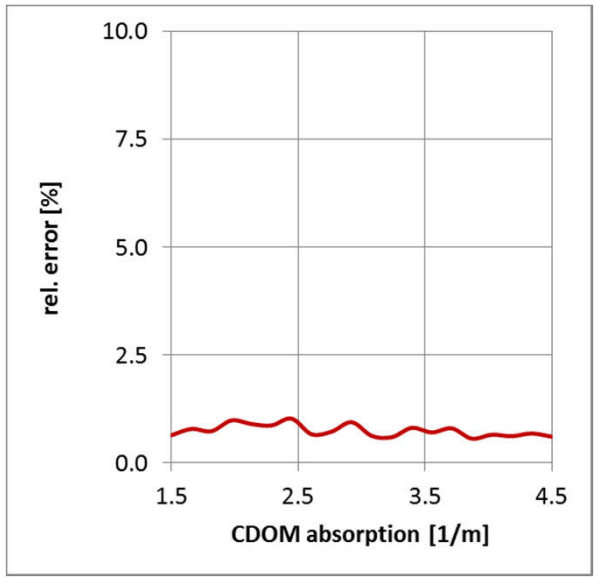


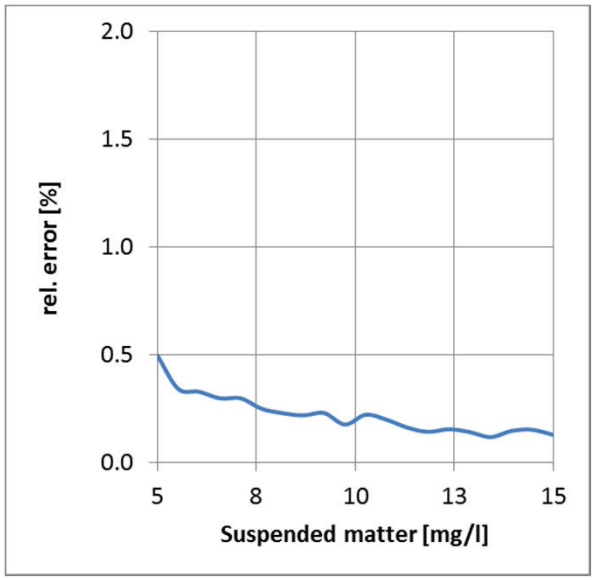


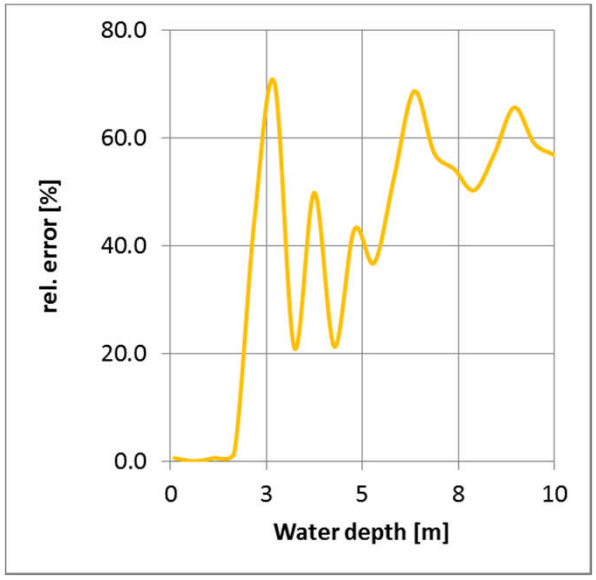
θ_{sun} [deg]	**30**	TSM [mg /l]	**10** (5-15)	a_{CDOM} [1/m]	**2.5** (1.5-4.5)
VIS [km]	**100**	CHL [mg /l]	**40**	zB [m]	**1** (0-10)

Inversion Results

Scenario C+ High Chl (2 Finnish Lakes) 1 fit parameter



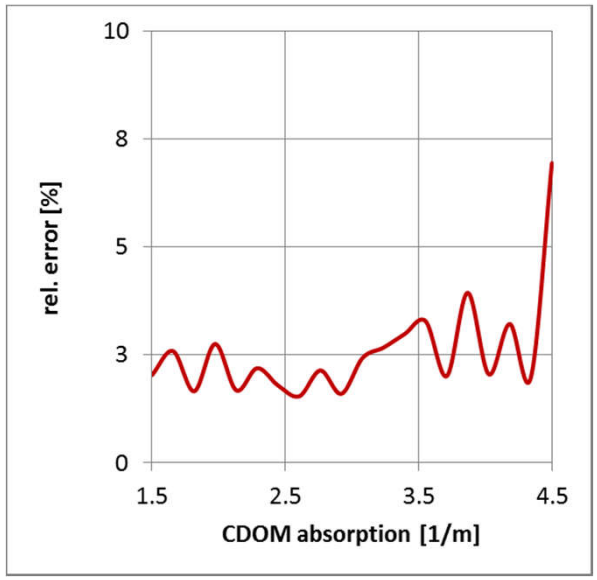


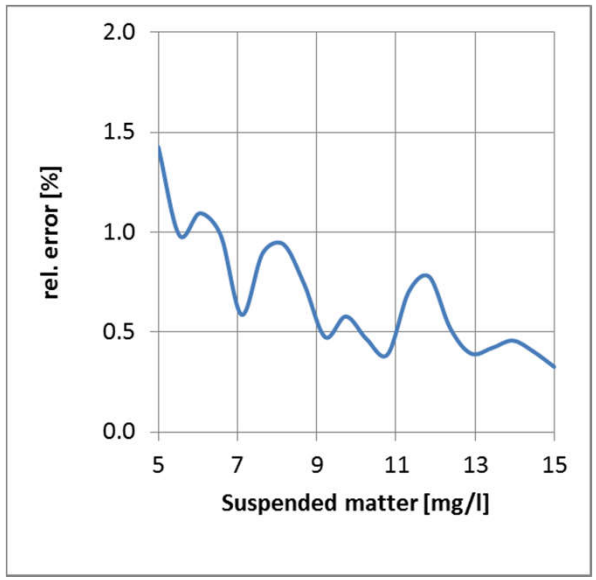


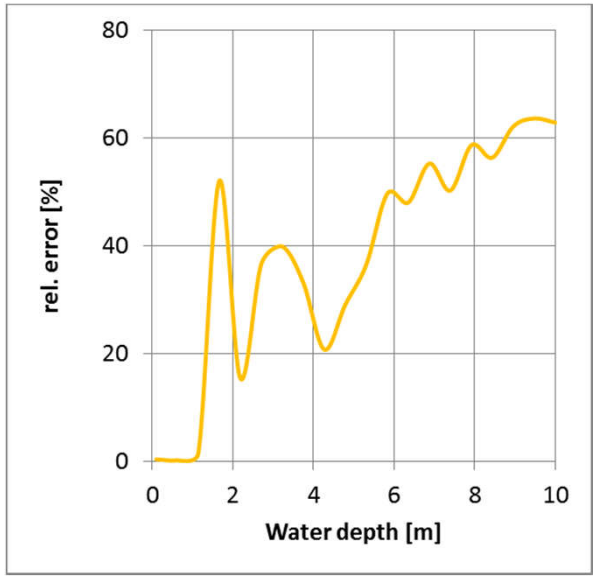
θ_{sun} [deg]	**30**	TSM [mg /l]	**10** (5-15)	a_{CDOM} [1/m]	**2.5** (1.5-4.5)
VIS [km]	**100**	CHL [mg /l]	**40**	zB [m]	**1** (0-10)

Inversion Results

Scenario C+ High Chl (2 Finnish Lakes) 3 fit parameter







θ_{sun} [deg]	**30**	TSM [mg /l]	**10** (5-15)	a_{CDOM} [1/m]	**2.5** (1.5-4.5)
VIS [km]	**100**	CHL [mg /l]	**40**	zB [m]	**1** (0-10)

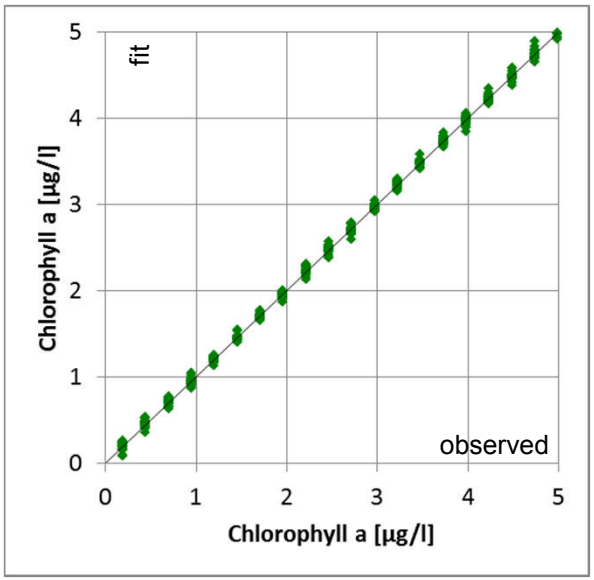
Scenarios

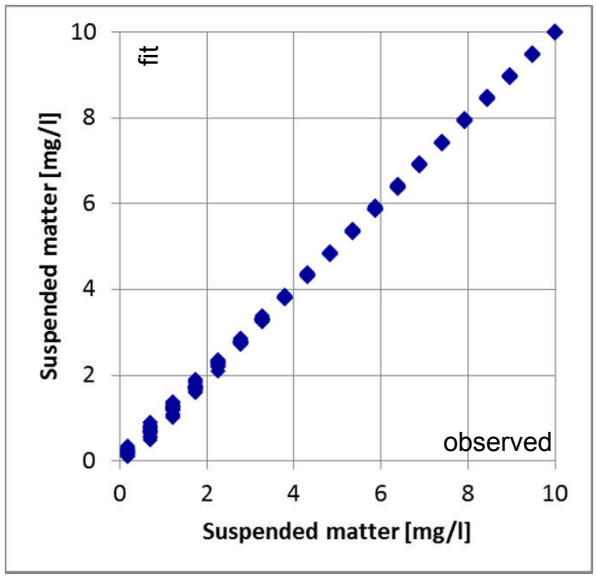
Scenario	X-	X+	Y-	Y+	C-	C+
Represents	**low TSM**	**high TSM**	**low a_{CDOM}**	**high a_{CDOM}**	**low CHL**	**high CHL**
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**1**(0.2-10.0)	**5**(1-10)	**1**(0.2-20.0)	**10**(5-15)
a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1 (0.1-10)**	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)	**0.014** (0.01-0.02)

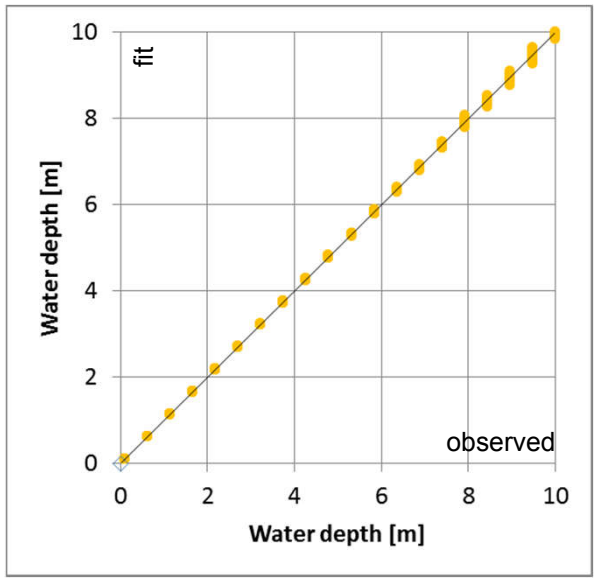
Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

Inversion Results

Scenario Y- Low CDOM (L. Maggiore) 1 fit parameter



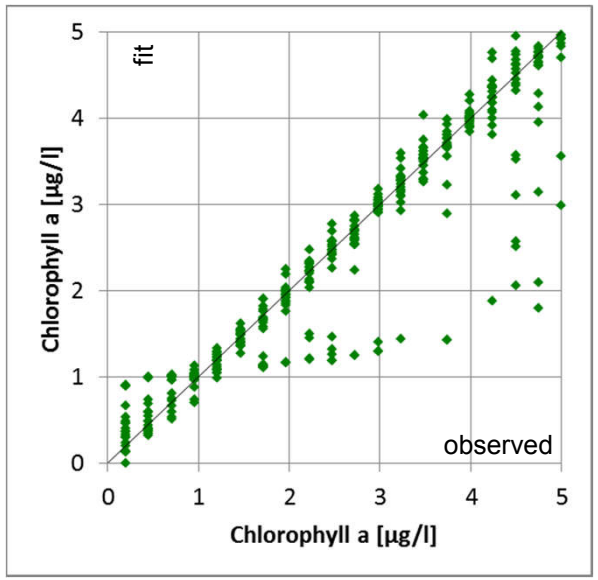


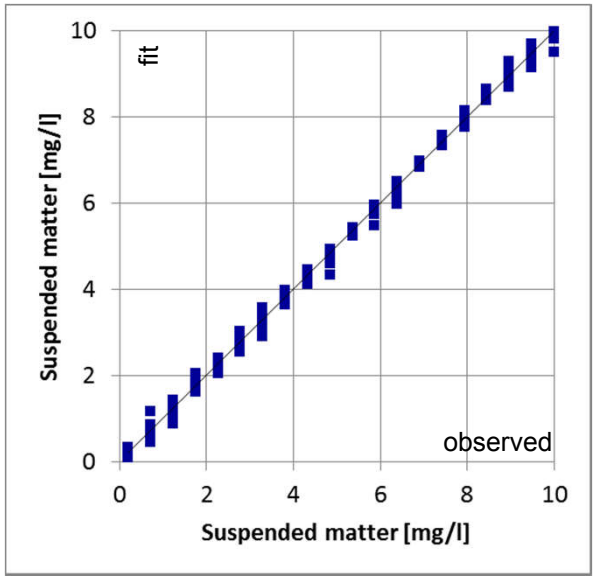


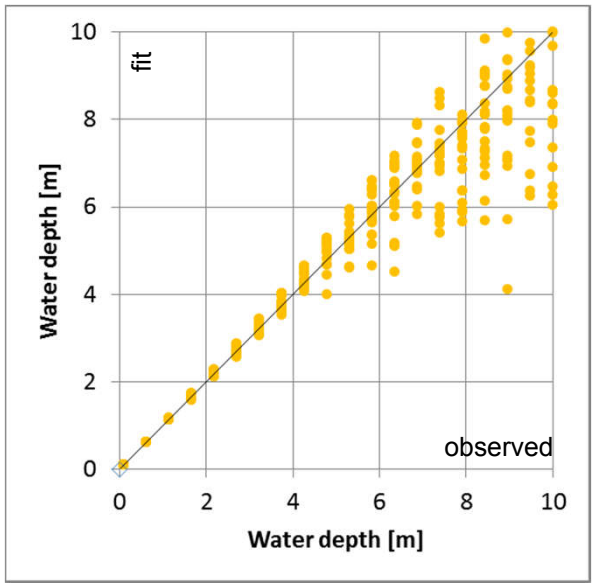
θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-10)	a_{CDOM} [1/m]	**0.2**
VIS [km]	**100**	CHL [mg /l]	**1**(0.2-5)	zB [m]	**1** (0-10)

Inversion Results

Scenario Y- Low CDOM (L. Maggiore) 3 fit parameter



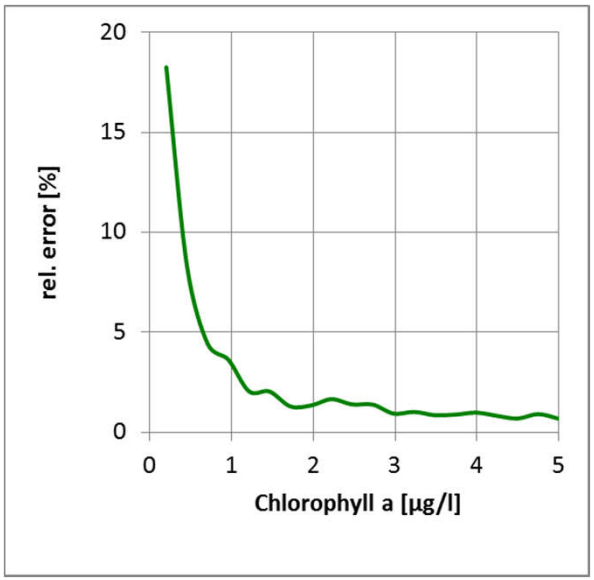


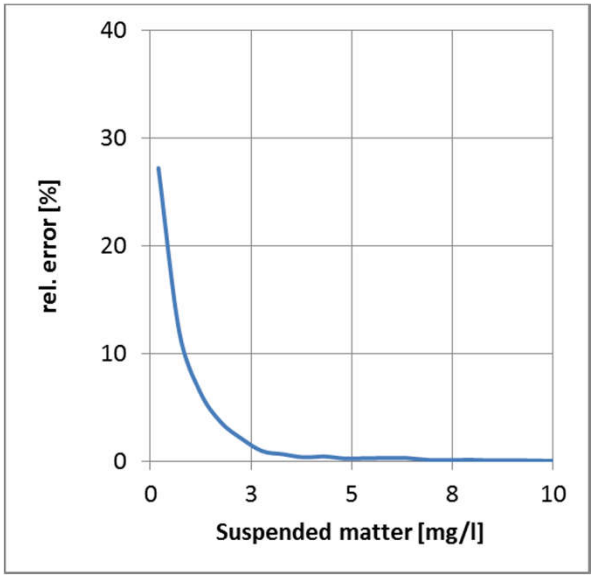


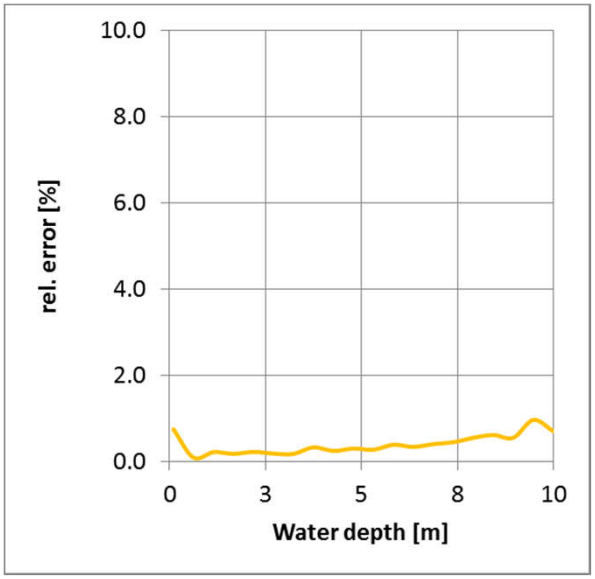
θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-10)	a_{CDOM} [1/m]	**0.2**
VIS [km]	**100**	CHL [mg /l]	**1**(0.2-5)	zB [m]	**1** (0-10)

Inversion Results

Scenario Y- Low CDOM (L. Maggiore) 1 fit parameter



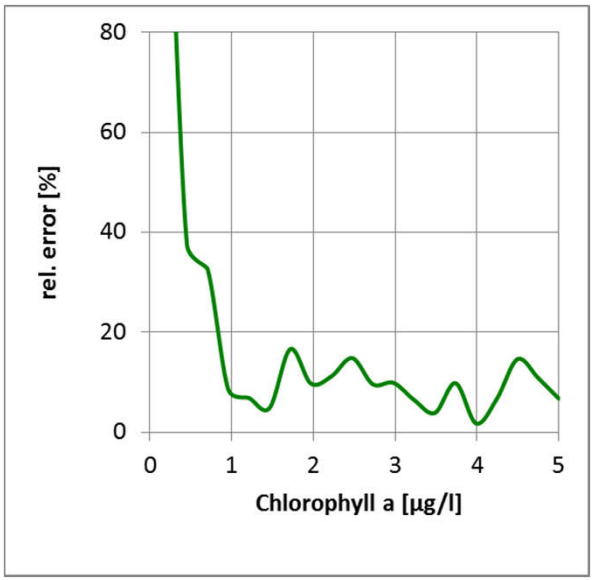


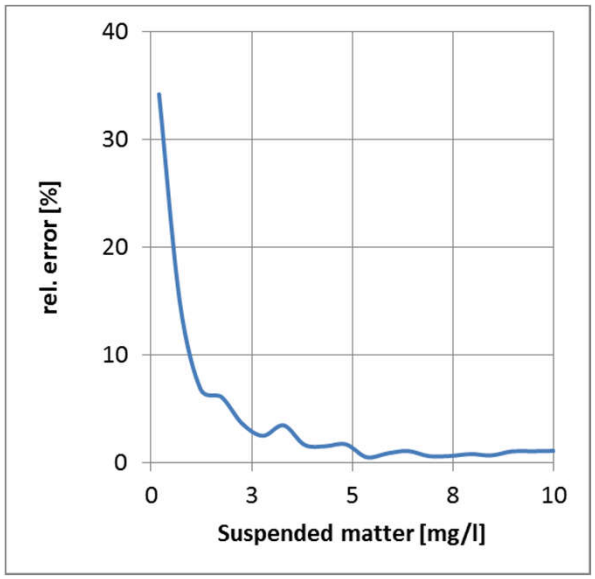


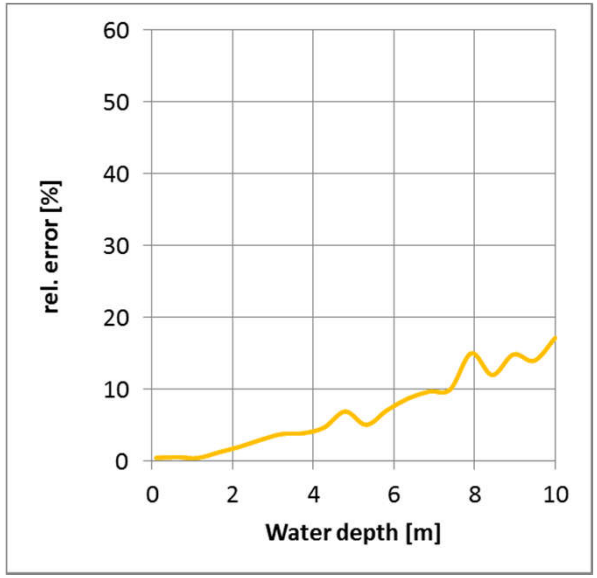
θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-10)	a_{CDOM} [1/m]	**0.2**
VIS [km]	**100**	CHL [mg /l]	**1**(0.2-5)	zB [m]	**1** (0-10)

Inversion Results

Scenario Y- Low CDOM (L. Maggiore) 3 fit parameter







θ_{sun} [deg]	**30**	TSM [mg /l]	**1** (0.2-10)	a_{CDOM} [1/m]	**0.2**
VIS [km]	**100**	CHL [mg /l]	**1**(0.2-5)	zB [m]	**1** (0-10)

Scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	low TSM	high TSM	low a_{CDOM}	high a_{CDOM}	low CHL	high CHL
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**1**(0.2-10.0)	**5**(1-10)	**1**(0.2-20.0)	**10**(5-15)
a_{CDOM} [m^{-1}]	**0.5**(0.2-2.0)	**2.5**(1-5)	**0.2**	**2.5**	**0.1**(0.04-2.00)	**2.5**(1.5-4.5)
CHL[mg m^{-3}]	**2**(0.5-15.0)	**5**(1-20)	**1**(0.2-5.0)	**5**(1-20)	**1**	**40**
zB [m]	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)	**1** (0.1-10)
S_{CDOM}[nm^{-1}]	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)

Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

Error analysis for 1 fit scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	low TSM	high TSM	low a_{CDOM}	high a_{CDOM}	low CHL	high CHL
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**6.5** (27-0.1)	**0.2** (1.4-0.3)	**0.3** (2-0.02)	**0.17** (0.5-0.2)
a_{CDOM} [m^{-1}]	**1.6** (1.2-2.7)	**0.6** (0.4-0.7)	**0.2**	**2.5**	**0.3** (0.6-2.2)	**1** (0.6-0.6)
CHL[mg m^{-3}]	**4.2** (15.9-1.7)	**5** (11-1.2)	**3.6** (18.2-0.6)	**2** (7.7-0.8)	**1**	**40**
zB [m]	**0.2** (0.8-3)	**0.2** (0.1-42.9)	**0.2** (0.1-0.7)	**0.3** (0.1-44)	**0.2** (0.6-0.7)	**0.7** (0.7-57)
S_{CDOM}[nm^{-1}]	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)

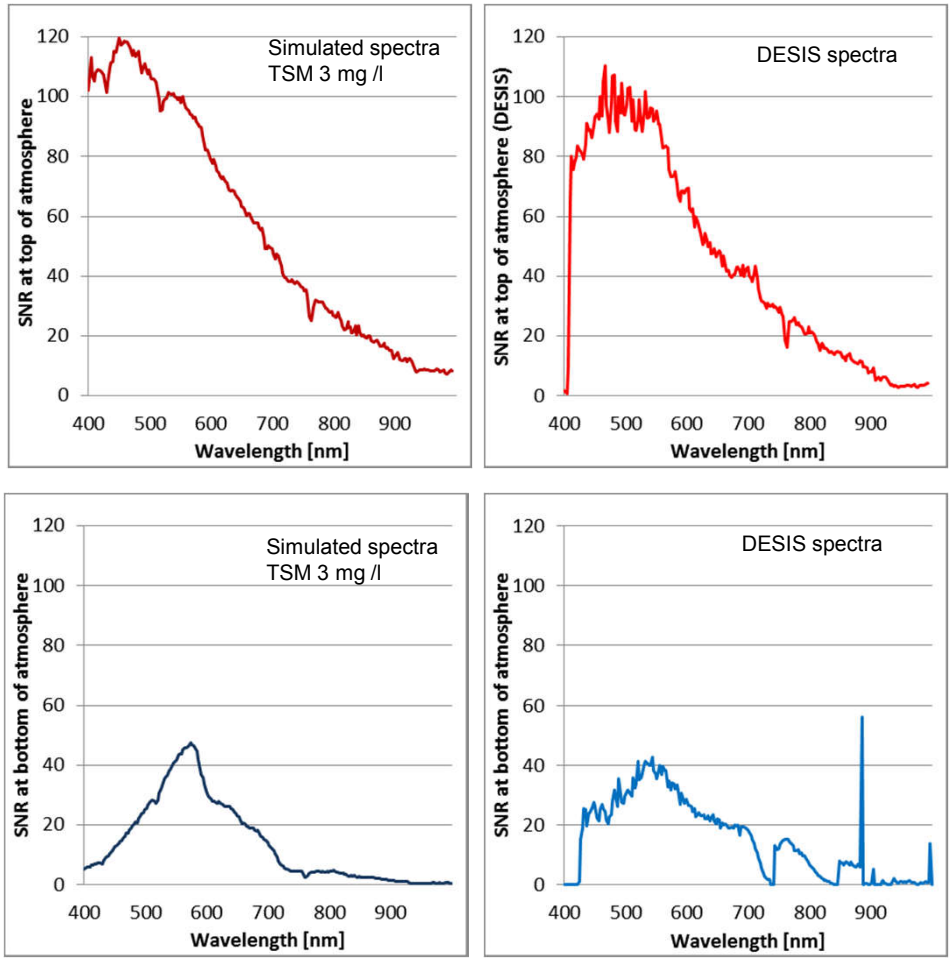
Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

Error analysis for 3 fit scenarios

Scenario	X-	X+	Y-	Y+	C-	C+
Represents	low TSM	high TSM	low a_{CDOM}	high a_{CDOM}	low CHL	high CHL
Example	L. Constance	Lake Peipsi	L. Maggiore	Lake Peipsi	Lake Garda	Finnish L.
TSM [g m^{-3}]	**1**	**5**	**6.8** (34-1.1)	**0.3** (2.1-0.3)	**0.8** (7.7-0.4)	**0.6** (1.4-0.3)
a_{CDOM} [m^{-1}]	**3.9** (11.5-22.2)	**1.4** (4.1-1.8)	**0.2**	**2.5**	**0.1** (7.9-6.5)	**1.8** (2-6.7)
CHL[mg m^{-3}]	**6.7** (287-62)	**5.2** (126-28)	**8.5** (127-6.7)	**2.3** (132-27)	**1**	**40**
zB [m]	**0.4** (0.3-15)	**0.5** (0.5-41)	**0.5** (0.47-17)	**0.5** (0.5-41)	**0.4** (0.3-14)	**1.5** (0.5-62)
S_{CDOM}[nm^{-1}]	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)	0.014 (0.01-0.02)

Standard scenarios for optically deep water. A scenario is defined by the value of a parameter marked as bold. The other parameters are specified by a typical value and a range in the notation typical (min-max)
http://ceos.org/about-ceos/publications-2/

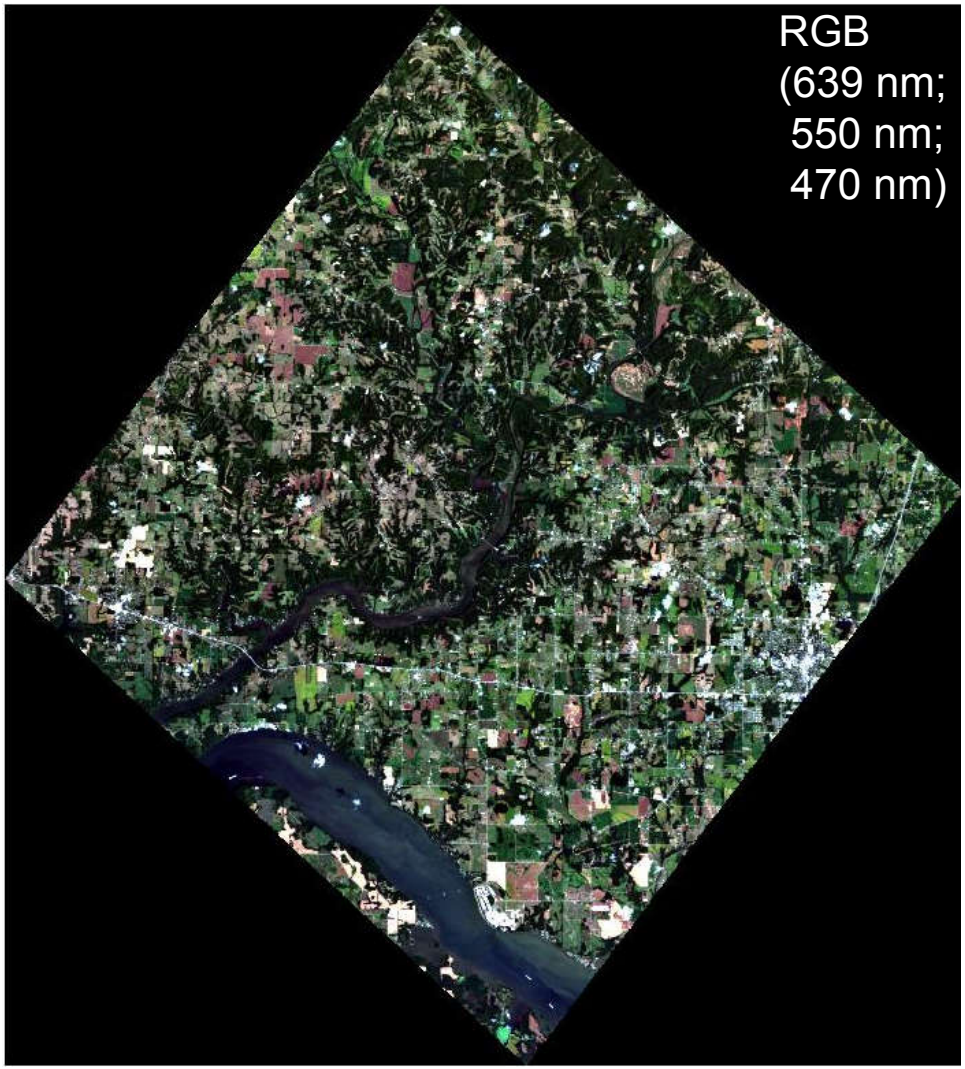
Inversion of water parameters from real DESIS spectra



RGB (639 nm; 550 nm; 470 nm)

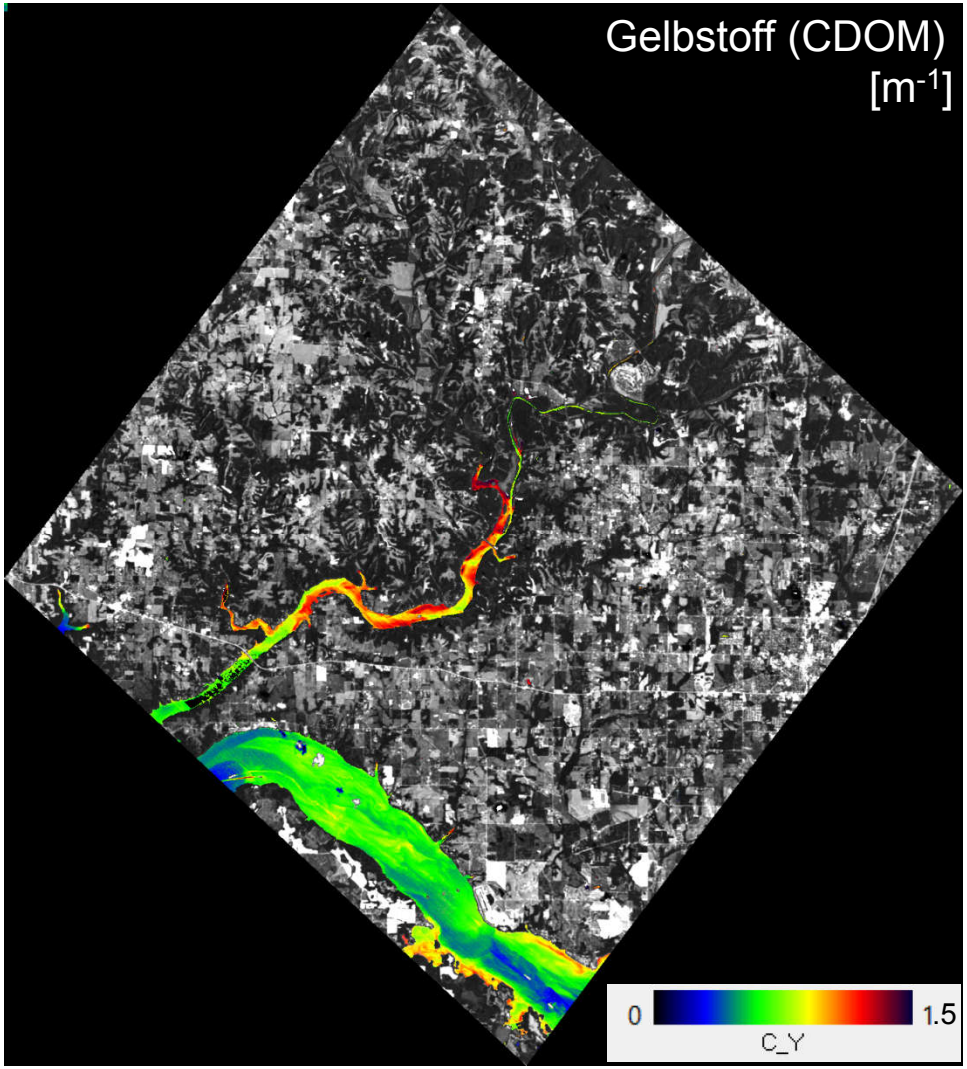
Tennesse River, Alabama (USA)
4th Sept. 2018

Inversion of water parameters from DESIS



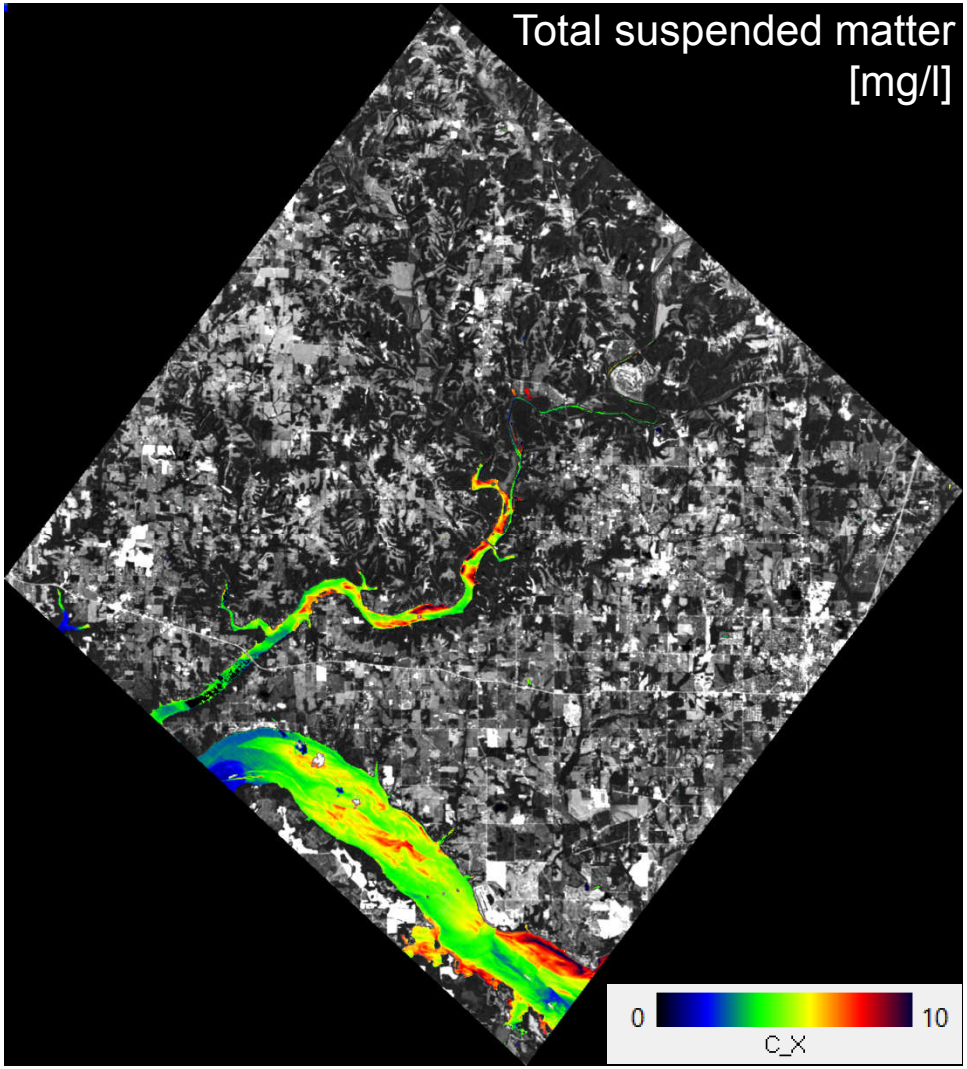
Tennessee River
Alabama (USA)

Inversion of water parameters from DESIS (not validated)



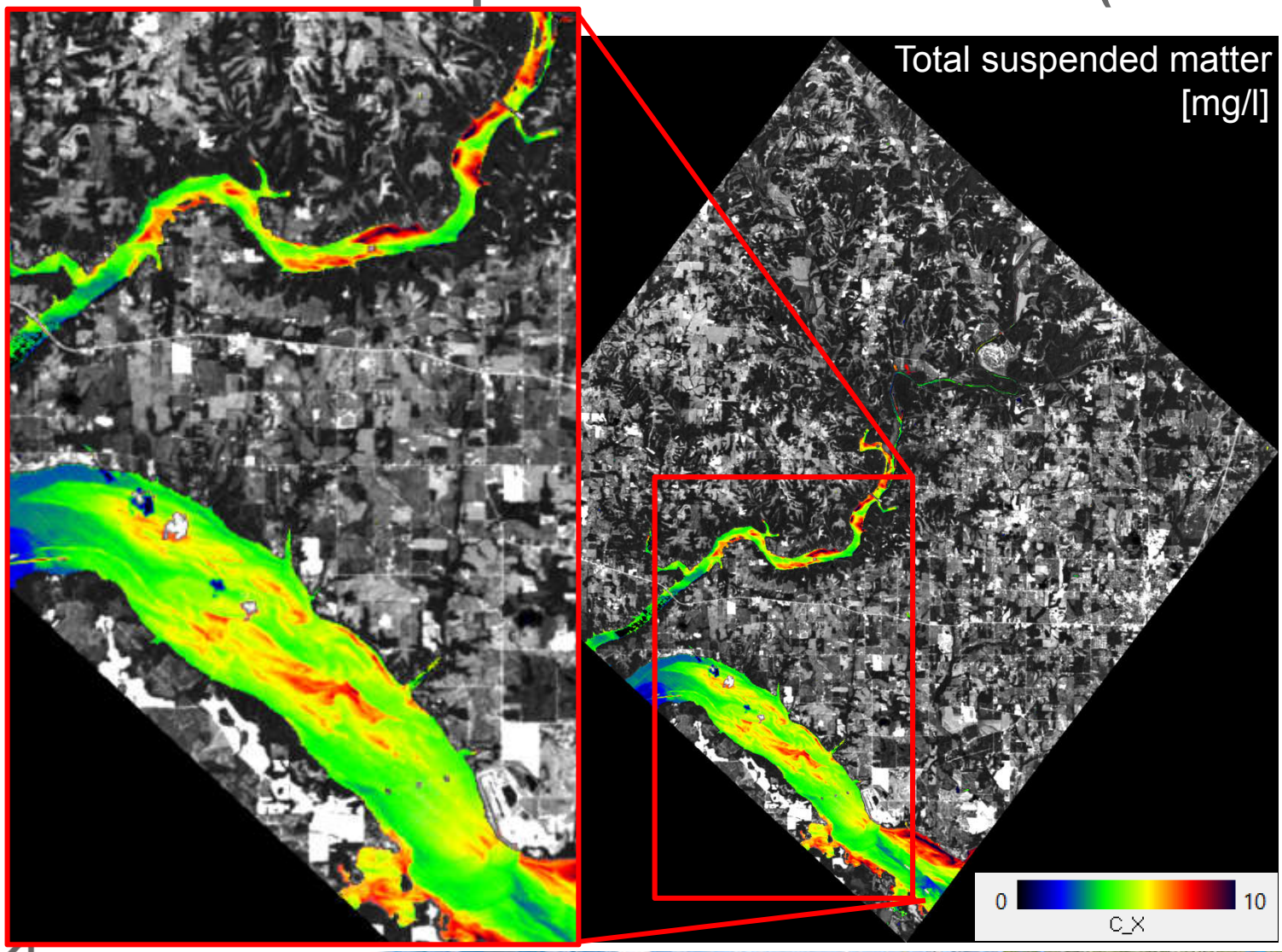
Tennessee River
Alabama (USA)

Inversion of water parameters from DESIS (not validated)



Tennessee River
Alabama (USA)

Inversion of water parameters from DESIS (not validated)



Summary

- Simulated retrieval of water constituents was tested on different water constituents concentration and different atmospheric conditions.
- Retrieval worked well within the derived range of error for CDOM, CHL, TSM and bathymetry
- First inversion results of water parameters from DESIS for TSM and CDOM are very promising

Outlook

- Extent sensitivity study to different environmental conditions (varying sunangle, visibility)
- SNR simulations of other sensors e.g. EnMAP, Sentinel, HySpex
- Comparison of simulated spectra to BOA radiances of other real DESIS data

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